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(54) Title: TRANSDERMAL DELIVERY OF PARTICULATE VACCINE COMPOSITIONS

(57) Abstract

A method for enhancing the immune response to a selected antigen is disclosed. The method entails delivering a particulate adjuvant composition transdermally, preferably using a needleless syringe system. Also described are methods for forming crystalline particles from pharmaceutical compositions and then delivering the same to a subject. The crystallized compositions are particularly suitable for transdermal vaccine delivery using a needleless syringe system.

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5   TRANSDERMAL DELIVERY OF PARTICULATE VACCINE COMPOSITIONS

Technical Field
            The invention relates to particulate
10   compositions. More particularly, the invention
      relates to methods of delivering particulate
      formulations, as well as methods for forming
      crystalline particles from pharmaceutical compositions
      and then delivering the same to a subject. The
15   particulate compositions are particularly suitable for
      transdermal vaccine delivery using a needleless
      syringe system.

Background of the Invention
20   The ability to deliver agents into and
      through skin surfaces (transdermal delivery) provides
      many advantages over parenteral delivery techniques.
      In particular, transdermal delivery provides a safe,
      convenient and noninvasive alternative to traditional
25   administration systems, conveniently avoiding the
      major problems associated with parenteral delivery,
      e.g., needle pain, the risk of introducing infection
      to treated individuals, the risk of contamination or
      infection of health care workers caused by accidental
30   needle-sticks and the disposal of used needles. In
      addition, such delivery affords a high degree of
      control over blood concentrations of administered
      drugs.
            Recently, a novel transdermal drug delivery
35   system that entails the use of a needleless syringe to
      fire solid drug-containing particles in controlled

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doses into and through intact skin has been described.
In particular, commonly owned U.S. Patent No.
5,630,796 to Bellhouse et al., describes a needleless
syringe that delivers pharmaceutical particles
5   entrained in a supersonic gas flow. The needleless
syringe (also referred to as "the PowderJect
needleless syringe device") is used for transdermal
delivery of powdered drug compounds and compositions,
for delivery of genetic material into living cells
10   (e.g., gene therapy) and for the delivery of
biopharmaceuticals to skin, muscle, blood or lymph.
The needleless syringe can also be used in conjunction
with surgery to deliver drugs and biologics to organ
surfaces, solid tumors and/or to surgical cavities
15   (e.g., tumor beds or cavities after tumor resection).
Pharmaceutical agents that can be suitably prepared in
a substantially solid, particulate form can be safely
and easily delivered using such a device.
                One particular needleless syringe generally
20   comprises an elongate tubular nozzle having a
rupturable membrane initially closing the passage
through the nozzle and arranged substantially adjacent
to the upstream end of the nozzle. Particles of a
therapeutic agent to be delivered are disposed
25   adjacent to the rupturable membrane and are delivered
using an energizing means which applies a gaseous
pressure to the upstream side of the membrane
sufficient to burst the membrane and produce a
supersonic gas flow (containing the pharmaceutical
30   particles) through the nozzle for delivery from the
downstream end thereof. The particles can thus be
delivered from the needleless syringe at delivery
velocities of between Mach 1 and Mach 8 which are
readily obtainable upon the bursting of the rupturable
35   membrane.

Another needleless syringe configuration
generally includes the same elements as described
above, except that instead of having the
pharmaceutical particles entrained within a supersonic
5   gas flow, the downstream end of the nozzle is provided
with a bistable diaphragm which is moveable between a
resting "inverted" position (in which the diaphragm
presents a concavity on the downstream face to contain
the pharmaceutical particles) and an active "everted"
10   position (in which the diaphragm is outwardly convex
on the downstream face as a result of a supersonic
shockwave having been applied to the upstream face of
the diaphragm). In this manner, the pharmaceutical
particles contained within the concavity of the
15   diaphragm are expelled at a supersonic initial
velocity from the device for transdermal delivery
thereof to a targeted skin or mucosal surface.

Transdermal delivery using the above-
described needleless syringe configurations is carried
20   out with particles having an approximate size that
generally ranges between 0.1 and 250 μm. Particles
larger than about 250 μm can also be delivered from
the device, with the upper limitation being the point
at which the size of the particles would cause
25   untoward damage to the skin cells. The actual
distance which the delivered particles will penetrate
depends upon particle size (e.g., the nominal particle
diameter assuming a roughly spherical particle
geometry), particle density, the initial velocity at
30   which the particle impacts the skin surface, and the
density and kinematic viscosity of the skin. Target
particle densities for use in needleless injection
generally range between about 0.1 and 25 g/cm^3, and
injection velocities generally range between about 200
35   and 3,000 m/sec.

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A particularly unique feature of the needleless syringe is the ability to closely control the depth of penetration of delivered particles, thereby allowing for targeted administration of
5   pharmaceuticals to various sites. For example, particle characteristics and/or device operating parameters can be selected to provide for varying penetration depths for, e.g., intradermal or subcutaneous delivery. One approach entails the
10 selection of particle size, particle density and initial velocity to provide a momentum density (e.g., particle momentum divided by particle frontal area) of between about 2 and 10 kg/sec/m, and more preferably between about 4 and 7 kg/sec/m. Such control over
15 momentum density allows for precisely controlled, tissue-selective delivery of the pharmaceutical particles.

The above-described systems provide a unique means for delivering vaccine antigens into or across
20 skin or tissue. However, many antigens require the use of immunological adjuvants in order to increase antigenic potency. Immunological adjuvants act to augment cell-mediated and humoral immune responses. Such adjuvants include depot adjuvants, compounds
25 which adsorb and/or precipitate administered antigens and which serve to retain the antigen at the injection site. Typical depot adjuvants include aluminum compounds and water-in-oil emulsions.

Depot adjuvants, although increasing
30 antigenicity, often provoke severe persistent local reactions, such as granulomas, abscesses and scarring, when injected subcutaneously or intramuscularly. Other adjuvants, such as lipopolysacharrides and muramyl dipeptides, can elicit pyrogenic responses
35 upon injection and/or Reiter's symptoms (influenza-like symptoms, generalized joint discomfort and

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sometimes anterior uveitis, arthritis and urethritis).
Accordingly, there is a continued need for effective
and safe delivery methods of adjuvants for enhancing
immune responses to a given antigen.

5

Summary of the Invention

The present invention provides unique
adjuvant and vaccine compositions as well as a unique

10 system for delivering particulate pharmaceutical
compositions, including vaccines and other therapeutic
agents. Novel methods for making particulate
pharmaceutical compositions are also provided.

In one embodiment, then, a method is

15 provided for enhancing the immunogenicity of a
selected antigen. The method comprises:

(a) administering an effective amount of the
antigen to a vertebrate subject; and

(b) administering an amount of a particulate

20 adjuvant composition sufficient to enhance the
immunogenicity of the antigen, wherein the adjuvant is
delivered into or across skin or tissue of the
vertebrate subject and further wherein the
administering is carried out using a transdermal

25 delivery technique.

The antigen and adjuvant may be present in
the same or different compositions and may be
administered to the same or different sites in the
vertebrate subject. Furthermore, the antigen may be

30 administered prior or subsequent to, or concurrently
with the adjuvant composition.

In particularly preferred embodiments, the
adjuvant and/or antigen are administered using a
needleless syringe delivery device.

35 In another embodiment, the subject invention
is directed to a method for eliciting an immune

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response in a vertebrate subject. The method
comprises transdermally delivering a particulate
vaccine composition into or across skin or tissue of
the vertebrate subject. The particulate vaccine
5   composition comprises:

(a) an effective amount of a selected
antigen; and

(b) an amount of an adjuvant sufficient to
enhance the immunogenicity of the antigen.

10   In yet another embodiment, the invention is
directed to a particulate adjuvant composition
suitable for delivery into or across skin or tissue of
a vertebrate subject using a transdermal delivery
technique. The particulate adjuvant composition can
15   be used to elicit a physiological effect in a
vertebrate subject by administering an amount of the
particulate adjuvant composition into or across skin
or tissue of the vertebrate subject sufficient to
bring about the physiological effect.

20   In another embodiment, a method is provided
for converting conventional pharmaceutical
formulations into crystallized particles that are
optimally suited for transdermal delivery using a
needleless syringe. Thus, in one aspect of the
25   invention, a liquid pharmaceutical formulation (e.g.,
either in aqueous form, or a reconstituted lyophilized
product), is combined with a suitable excipient, for
example a sugar, and then dried to provide a
crystalline composition. The excipient is selected to
30   provide for sufficient rigidity, structure, and
density in the resulting crystalline product. The
crystalline composition, now having a sufficient
density, can be used directly in a needleless syringe
delivery technique, or can be further processed to
35   provide a more finely divided and/or uniform
crystalline composition.

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In a further embodiment of the invention, a crystalline pharmaceutical composition is delivered to a subject in order to bring about a desired treatment. In one particular aspect, a crystalline vaccine

5   composition is delivered to a subject via needleless injection in order to provide for a biological response in the subject. In a preferred embodiment, the crystalline vaccine composition is delivered to the subject to elicit an antigen-specific immune

10   response in the subject.

In yet another embodiment of the invention, a crystalline pharmaceutical composition is provided. The crystalline pharmaceutical has sufficient particle structure, rigidity and/or density characteristics

15   which renders it suitable for delivery into and/or through skin or mucosal tissue using a needleless syringe system. The crystalline pharmaceutical composition of the present invention can be made using the methods of the invention, and thus includes

20   vaccine compositions.

These and other embodiments of the invention will readily occur to those of ordinary skill in the art in view of the disclosure herein.

25   <u>Brief Description of the Drawings</u>

Figures 1A and 1B depict the results of Example 1 where the effect of particle size on IgG antibody response was assessed in particulate vaccine formulations.

30   Figures 2-4 depict ELISA results from sera obtained from mice immunized with a crystalline Hib conjugate vaccine composition delivered using a needleless syringe. In Figure 2, the PRP-CRM197 conjugate was used as the capture phase, in Figure 3,

35   diphtheria toxoid was used as the capture phase, and

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in Figure 4, a PRP-HSA conjugate was used as the
capture phase.

Figure 5 depicts the IgG antibody response
in subjects receiving descending doses of the Hib
5   conjugate vaccine compositions in either particulate
or liquid form.

Figures 6A and 6B depict the duration of
immunity provided by the Hib conjugate vaccine
compositions in either particulate or liquid form.
10   Figure 7 depicts antibody responses to an
inactivated influenza virus vaccine composition
delivered in either particulate or liquid form. The
data represent geometric mean serum IgG titers from
pooled sera.
15   Figures 8A and 8B depict the results of an
influenza virus challenge study in subjects immunized
with an inactivated influenza virus vaccine
composition delivered in either particulate or liquid
form. Subjects in Figure 8A received 25 μg of
20   inactivated virus, while subjects in Figure 8B
received 5 μg of inactivated virus. The data
represent weight loss as mean percentage of initial
body weight.

Figure 9 depicts the results of an influenza
25   virus challenge study in subjects immunized with an
inactivated influenza virus vaccine composition
adjuvanted with an Alum adjuvant and delivered in
either particulate or liquid form. The data represent
weight loss as the mean percentage of initial body
30   weight from eight animals.

Figure 10 depicts the results of an
influenza virus challenge study in subjects immunized
with an inactivated influenza virus vaccine
composition adjuvanted with a PCPP adjuvant and
35   delivered in either particulate or liquid form. The

data represent weight loss as the mean percentage of initial body weight from eight animals.

Figures 11A and 11B depict the results of influenza virus challenge studies in subjects immunized with an inactivated influenza virus vaccine composition adjuvanted with a CpG adjuvant and delivered in either particulate (Figure 11A) or liquid (Figure 11B) form. The data represent weight loss as the mean percentage of initial body weight from eight animals.

Figure 12 depicts the results of an influenza virus challenge study in subjects immunized with an inactivated influenza virus vaccine composition adjuvanted with a MPL adjuvant and delivered in either particulate or liquid form. The data represent weight loss as the mean percentage of initial body weight from eight animals.

Detailed Description of the Preferred Embodiments

Before describing the present invention in detail, it is to be understood that this invention is not limited to particular pharmaceutical formulations or process parameters as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments of the invention only, and is not intended to be limiting.

It must be noted that, as used in this specification and the appended claims, the singular forms "a", "an" and "the" include plural referents unless the content clearly dictates otherwise. Thus, for example, reference to "a pharmaceutical agent" includes a mixture of two or more pharmaceutical agents, reference to "an antigen" includes a mixture of two or more antigens, reference to "an excipient"

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includes mixtures of two or more excipients, and the like.

A. Definitions

5   Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although a number of methods and materials similar or equivalent

10   to those described herein can be used in the practice of the present invention, the preferred materials and methods are described herein.

In describing the present invention, the following terms will be employed, and are intended to

15   be defined as indicated below.

By "transdermal delivery" is meant delivery of particles to target tissue to provide a local, regional or systemic response. This contrasts with the direct introduction of substances across cell

20   membranes into living cells and tissue which is designed to operate on an intracellular level. Preferably, the particle size of the administered substance is larger than the cells present in the targeted tissue. Generally, for mammalian cells,

25   particles larger than 10 μM will achieve this desired effect. Suitable size ranges for particles are discussed further below.

Thus, the term "transdermal" delivery intends intradermal (e.g., into the dermis or

30   epidermis), transdermal (e.g., "percutaneous") and transmucosal administration, i.e., delivery by passage of an agent into or through skin or mucosal tissue. See, e.g., Transdermal Drug Delivery: Developmental Issues and Research Initiatives, Hadgraft and Guy

35   (eds.), Marcel Dekker, Inc., (1989); Controlled Drug Delivery: Fundamentals and Applications, Robinson and

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Lee (eds.), Marcel Dekker Inc., (1987); and
Transdermal Delivery of Drugs, Vols. 1-3, Kydonieus
and Berner (eds.), CRC Press, (1987).

By "needleless syringe" is meant an
5   instrument which delivers a particulate composition
transdermally, without a conventional needle that
pierces the skin. Needleless syringes for use with
the present invention are discussed througout this
document.

10   As used herein, the term "pharmaceutical
agent" intends any compound or composition of matter
which, when administered to an organism (human or
animal) induces a desired pharmacologic and/or
physiologic effect by local and/or systemic action.
15   The term therefore encompasses those compounds or
chemicals traditionally regarded as drugs and
vaccines, as well as biopharmaceuticals including
molecules such as peptides, hormones, nucleic acids,
gene constructs and the like.

20   By "antigen" is meant a molecule which
contains one or more epitopes that will stimulate a
host's immune system to make a cellular
antigen-specific immune response, or a humoral
antibody response. Thus, antigens include proteins,
25   polypeptides, antigenic protein fragments,
oligosaccharides, polysaccharides, and the like.
Furthermore, the antigen can be derived from any known
virus, bacterium, parasite, plants, protozoans, or
fungus, and can be a whole organism. The term also
30   includes tumor antigens. Similarly, an
oligonucleotide or polynucleotide which expresses an
antigen, such as in DNA immunization applications, is
also included in the definition of antigen. Synthetic
antigens are also included, for example, polyepitopes,
35   flanking epitopes, and other recombinant or
synthetically derived antigens (Bergmann et al. (1993)

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Eur. J. Immunol. 23:2777-2781; Bergmann et al. (1996)
J. Immunol. 157:3242-3249; Suhrbier, A. (1997)
Immunol. and Cell Biol. 75:402-408; Gardner et al.
(1998) 12th World AIDS Conference, Geneva,

5 Switzerland, June 28-July 3, 1998).

The term "vaccine composition" intends any
pharmaceutical composition containing an antigen,
which composition can be used to prevent or treat a
disease or condition in a subject. The term thus

10 encompasses both subunit vaccines, i.e., vaccine
compositions containing antigens which are separate
and discrete from a whole organism with which the
antigen is associated in nature, as well as
compositions containing whole killed, attenuated or

15 inactivated bacteria, viruses, parasites or other
microbes.

Viral vaccine compositions used herein
include, but are not limited to, those containing, or
derived from, members of the families Picornaviridae

20 (e.g., polioviruses, etc.); Caliciviridae; Togaviridae
(e.g., rubella virus, dengue virus, etc.);
Flaviviridae; Coronaviridae; Reoviridae; Birnaviridae;
Rhabodoviridae (e.g., rabies virus, etc.);
Filoviridae; Paramyxoviridae (e.g., mumps virus,

25 measles virus, respiratory syncytial virus, etc.);
Orthomyxoviridae (e.g., influenza virus types A, B and
C, etc.); Bunyaviridae; Arenaviridae; Retroviradae
(e.g., HTLV-I; HTLV-II; HIV-1; and HIV-2); simian
immunodeficiency virus (SIV) among others.

30 Additionally, viral antigens may be derived from
papillomavirus (e.g., HPV); a herpesvirus; a hepatitis
virus, e.g., hepatitis A virus (HAV), hepatitis B
virus (HBV), hepatitis C virus (HCV), the delta
hepatitis virus (HDV), hepatitis E virus (HEV) and

35 hepatitis G virus (HGV); and the tick-borne
encephalitis viruses. See, e.g. Virology, 3rd Edition

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(W.K. Joklik ed. 1988); *Fundamental Virology*, 2nd
Edition (B.N. Fields and D.M. Knipe, eds. 1991), for a
description of these and other viruses. Bacterial
vaccine compositions used herein include, but are not
limited to, those containing or derived from organisms
that cause diphtheria, cholera, tuberculosis, tetanus,
pertussis, meningitis, and other pathogenic states,
including, *Meningococcus* A, B and C, *Hemophilus
influenza* type B (HIB), and *Helicobacter pylori*.
Examples of anti-parasitic vaccine compositions
include those derived from organisms causing malaria
and Lyme disease.

A composition which contains a selected
antigen along with an adjuvant, or a vaccine
composition which is coadministered with the subject
adjuvant, displays "enhanced immunogenicity" when it
possesses a greater capacity to elicit an immune
response than the immune response elicited by an
equivalent amount of the antigen administered without
the adjuvant. Thus, a vaccine composition may display
"enhanced immunogenicity" because the antigen is more
strongly immunogenic or because a lower dose or fewer
doses of antigen are necessary to achieve an immune
response in the subject to which the antigen is
administered. Such enhanced immunogenicity can be
determined by administering the adjuvant composition
and antigen controls to animals and comparing antibody
titers and/or cellular-mediated immunity against the
two using standard assays such as radioimmunoassay,
ELISAs, CTL assays, and the like, well known in the
art.   For purposes of the present invention, an
"effective amount" of an adjuvant will be that amount
which enhances an immunological response to a
coadministered antigen such that the antigen displays
enhanced immunogenicity as described above.

Similarly, an "effective amount" of an antigen is an amount which will stimulate an immune response in the subject to which the antigen is administered. The immune response may be a humoral,

5   cell-mediated and/or protective immune response.

As used herein, the term "coadministered" such as when an adjuvant is coadministered with a vaccine antigen, intends either the simultaneous or concurrent administration of adjuvant and antigen,

10   e.g., when the two are present in the same composition or administered in separate compositions at nearly the same time but at different sites, as well as the delivery of adjuvant and antigen in separate compositions at different times. For example, the

15   adjuvant composition may be delivered prior to or subsequent to delivery of the antigen at the same or a different site. The timing between adjuvant and antigen deliveries can range from about several minutes apart, to several hours apart, to several days

20   apart. Furthermore, although the adjuvant composition is delivered to the skin using transdermal delivery methods such as a needleless syringe, the vaccine composition may be delivered using conventional delivery techniques, such as by conventional syringes

25   and conventional vaccine guns.

As used herein, the term "treatment" includes any of following: the prevention of infection or reinfection; the reduction or elimination of symptoms; and the reduction or complete elimination of

30   a pathogen. Treatment may be effected prophylactically (prior to infection) or therapeutically (following infection).

By "vertebrate subject" is meant any member of the subphylum cordata, particularly mammals,

35   including, without limitation, humans and other primates. The term does not denote a particular age.

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Thus, both adult and newborn individuals are intended
to be covered.

        Pharmaceutical agents, alone or in
combination with other drugs or agents, are typically
5   prepared as pharmaceutical compositions which can
contain one or more added materials such as carriers,
vehicles, and/or excipients. "Carriers," "vehicles"
and "excipients" generally refer to substantially
inert materials which are nontoxic and do not interact
10   with other components of the composition in a dele-
terious manner. These materials can be used to
increase the amount of solids in particulate
pharmaceutical compositions, such as those prepared
using spray-drying or lyophilization techniques.
15   Examples of normally employed "excipients" or
"carriers" include pharmaceutical grades of dextrose,
sucrose, lactose, trehalose, mannitol, sorbitol,
inositol, dextran, starch, cellulose, sodium or
calcium phosphates, calcium sulfate, citric or
20   tartaric acids (and pharmaceutically acceptable salts
thereof), glycine, high molecular weight polyethylene
glycols (PEG), and combinations thereof. Exemplary
excipients that serve as stabilizers include commonly
available cryoprotectants and antioxidants.

25

B.   General Methods

        The invention provides for delivery of
particulate pharmaceutical compositions, particularly
vaccine compositions. These particualte compositions
30   can be delivered to a subject using a transdermal
needleless syringe delivery device. The ability to
transdermally administer vaccine compositions in
particulate (powder) form to tissue such as the skin
provides a significant improvement over prior
35   vaccination methods which generally rely on
conventional needle and syringe injection techniques.

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In this regard, almost all current vaccines are
administered by intramuscular injection. However,
injected vaccines need to get to local draining lymph
nodes in order to initiate an immune response. A

5   large portion of a vaccine composition injected
intramuscularly will rapidly diffuse into surrounding
tissue and circulation, thus becoming lost or diluted.
In contrast, when vaccine compositions are delivered
transdermally, e.g., to skin, such losses will not

10   occur. This is because the top layers of skin have
stronger antigen retaining ability due to poor
vascularity. Particulate vaccine compositions are
also better retained in the skin because of a slower
dissolving process. The cellular component in the

15   skin may also contribute to improved vaccine
performance following transdermal administration.
This is because there is a dense network of Langerhans
cells in the epidermal layer and dendritic cells in
the cutaneous layer of skin. These cells are

20   important in the initiation and maintenance of an
immune response. By delivering vaccine compositions
in the proximity of these immune cells, it is feasible
to achieve a stronger immune response than by
conventional intramuscular injection. These immune

25   cells may also pick up the vaccine and migrate to the
local draining lymph node, thereby initiating an
immune response.

          Transdermal administration of particulate
compositions to skin or mucosal tissue also improves

30   the safety and efficacy of commonly used
immunomodulators such as adjuvants. Immunomodulators
are often important components of vaccines and immune
therapeutics. Immunomodulators have many functions
including, for example, immune enhancement,

35   immunosuppression, and immune modulation. Immune
enhancement improves the efficacy of a vaccine or

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immunotherapeutics. Immune enhancement also enables
the immune system to respond to smaller doses of
vaccine compositions. For example, the aluminum
(Alum) adjuvant immunomodulator is used to formulate
5   diphtheria and tetanus toxoid vaccines to improve
their immunogenicity. Some immunomodulators that have
immunosuppressive properties are also useful in
treating certain diseases, such as autoimmune diseases
and organ transplantation. Immunomodulators can also
10   direct the immune systems to generate either a Th1- or
Th2-type of response, or to switch one type of
established response to another type. This immune
modulating property is very important in
immunotherapy. For example, subjects having an immune
15   system biased toward a Th2-type response tend to have
allergies. Immunomodulators which can help promote a
Th1-type response are thus useful in immune therapy to
desensitize those individuals.

        As with conventional vaccine compositions,
20   immunomodulators are typically administered by
intramuscular injection. One of the problems with
this injection method is the toxicity of
immunomodulators after they have reached systemic
circulation. It is for this reason that many
25   immunomodulators can not be used in humans.
Intramuscular injection also requires a high dose of
immunomodulators (relative to transdermally delivered
immunomodulators) in order to be effective since a
large portion of injected material will rapidly
30   diffuse from the injection site, generally entereing
into the circulation. In this regard, an adjuvant may
need to exert its activities at the injection site or
in the local draining lymph node(s) to enhance vaccine
performance.

35   Transdermal delivery of immunomodulators to
skin or mucosal tissue in accordance with the present

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invention is advantageous for the following reasons.
First, the skin and mucosa are very potent parts of
the immune system. As discussed above, there is a
dense network of immune cells in the various layers of
5   skin (e.g., Langerhans cells in the epidermal layer
and dendritic cells in the cutaneous layer). Mucosal
epithelium cells contain large number of
intraepithelial dendritic cells. These cells are
important in the initiation and maintenance of an
10   immune response, making them prime targets for
immunomodulation. By delivering immunomodulators in
close proximity to these cells, and avoiding rapid
loss by diffusion, it is feasible to achieve a
stronger immunomodulation effect than by intramuscular
15   injection. The effective dose of immunomodulators can
also be significantly reduced. A lower dose helps
reduce toxicity associated with many immunomodulators.

Accordingly, in one embodiment, the
20   invention entails a procedure for forming crystalline
particles (suitable for transdermal delivery) from
conventional pharmaceutical preparations. Although
the methods of the invention are broadly applicable to
any pharmaceutical composition, the invention is
25   exemplified herein with particular reference to
methods which use liquid (aqueous) or reconstituted
dried vaccine compositions as starting materials.
One common method of preparing and storing
vaccine pharmaceuticals involves lyophilization
30   (freeze-drying). Lyophilization relates to a
technique for removing moisture from a material and
involves rapid freezing at a very low temperature,
followed by rapid dehydration by sublimation in a high
vacuum. This technique typically yields low-density
35   porous particles having an open matrix structure.
Such particles are chemically stable, but are rapidly

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reconstituted (disintegrated and/or brought into solution) when introduced into an aqueous environment.

Another method of preparing and storing vaccine compositions from delicate or heat-sensitive biomolecules is spray-drying. Spray-drying relates to the atomization of a solution of one or more solids using a nozzle, spinning disk or other device, followed by evaporation of the solvent from the droplets. More particularly, spray-drying involves combining a highly dispersed liquid pharmaceutical preparation (e.g., a solution, slurry, emulsion or the like) with a suitable volume of hot air to produce evaporation and drying of the liquid droplets. Spray-dried pharmaceuticals are generally characterized as homogenous spherical particles that are frequently hollow. Such particles have low density and exhibit a rapid rate of solution.

In one method of the invention, a liquid composition, (an aqueous or a reconstituted spray-dried or lyophilized composition) is converted into a dry, crystalline powder suitable for delivery into and/or through skin or mucosal tissues. The liquid composition can be combined with a suitable carrier or excipient which provides for enhanced crystal formation, particle structure, rigidity and/or density characteristics. Preferred carriers or excipients include pharmaceutical-grade sugars and the like including, for example, trehalose. The composition is then allowed to dry under suitable evaporative conditions, resulting in a crystallized composition. The crystals can then be removed from the drying surface or container, and lightly broken up, for example, using mortar and pestle. The resulting crystalline powder can then be loaded into suitable delivery cassettes for delivery to a subject using a needleless syringe.

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Although not limiting in the present
invention, the above-described method can be used to
obtain crystalline particles having a size ranging
from about 0.1 to about 250 μm, preferably about 10 to
5   about 250 μm and a particle density ranging from about
0.1 to about 25 g/cm^3. These crystalline particles can
be used in the treatment or prevention of a variety of
diseases.
In another embodiment, the invention
10   pertains to delivery of particulate compositions,
particularly adjuvant and vaccine compositions. The
adjuvant and vaccine compositions may be in
crystalline form, as described above, or may be
delivered in an uncrystallized, particulate state.
15   Antigens for use with the present invention
can be produced using a variety of methods known to
those of skill in the art. In particular, the
antigens can be isolated directly from native sources,
using standard purification techniques.
20   Alternatively, the antigens can be produced
recombinantly using known techniques. See, e.g.,
Sambrook, Fritsch & Maniatis, *Molecular Cloning: A
Laboratory Manual*, Vols. I, II and III, Second Edition
(1989); *DNA Cloning*, Vols. I and II (D.N. Glover ed.
25   1985). Antigens for use herein may also be
synthesized, based on described amino acid sequences,
via chemical polymer syntheses such as solid phase
peptide synthesis. Such methods are known to those of
skill in the art. See, e.g., J. M. Stewart and J. D.
30   Young, *Solid Phase Peptide Synthesis*, 2nd Ed., Pierce
Chemical Co., Rockford, IL (1984) and G. Barany and R.
B. Merrifield, *The Peptides: Analysis, Synthesis,
Biology*, editors E. Gross and J. Meienhofer, Vol. 2,
Academic Press, New York, (1980), pp. 3-254, for solid
35   phase peptide synthesis techniques; and M. Bodansky,
Principles of Peptide Synthesis, Springer-Verlag,

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Berlin (1984) and E. Gross and J. Meienhofer, Eds.,
The Peptides: Analysis, Synthesis, Biology, supra,
Vol. 1, for classical solution synthesis.

Once obtained, the antigen of interest is
5   formed into a particulate vaccine composition as
described herein and administered to a subject,
generally along with an immunological adjuvant which
serves to enhance the immune response to the antigen.
As explained above, the adjuvant can be present in the
10   same or a separate composition and can be delivered
simultaneously with the vaccine composition, or prior
or subsequent to antigen delivery. Additionally,
adjuvant delivery can be at the same or a different
site.

15   Unfortunately, most known adjuvants are
highly toxic. Thus, the only adjuvant currently
approved for human usage is alum, an aluminum salt
composition.
A number of adjuvants are, however, used in animal
20   studies and several adjuvants for human use are
undergoing preclinical and clinical studies.

Surprisingly, adjuvants which are
generally considered too toxic for human use may be
administered with the present methods. Without being
25   bound by a particular theory, it appears that delivery
of adjuvants to the skin, using transdermal delivery
methods, allows interaction with Langerhans cells in
the epidermal layer and dendritic cells in the
cutaneous layer of the skin. These cells are
30   important in initiation and maintenance of an immune
response. Thus, an enhanced adjuvant effect can be
obtained by targeting delivery to or near such cells.
Additionally, because the top layers of the skin are
poorly vascularized, the amount of adjuvant entering
35   the systemic circulation is reduced, thereby reducing
the toxic effect. Furthermore, because skin cells are

constantly being sloughed, residual adjuvant is
eliminated rather than absorbed. Moreover, less
adjuvant can be administered than that delivered using
conventional techniques such as intramuscular

5   injection.   Accordingly, the present invention may
effectively be used with a large variety of adjuvants
without concomitant toxicity. Such adjuvants include,
without limitation, adjuvants formed from aluminum
salts (alum), such as aluminum hydroxide, aluminum

10 phosphate, aluminum sulfate, etc; oil-in-water and
water-in-oil emulsion formulations, such as Complete
Freunds Adjuvant (CFA) and Incomplete Freunds Adjuvant
(IFA); adjuvants formed from bacterial cell wall
components such as adjuvants including monophosphoryl

15 lipid A (MPL) (Imoto et al. (1985) *Tet. Lett.* $\underline{26}$:1545-
1548), trehalose dimycolate (TDM), and cell wall
skeleton (CWS); adjuvants derived from ADP-
ribosylating bacterial toxins, a group of potent
toxins to humans, include diphtheria toxin, pertussis

20 toxin (PT), cholera toxin (CT), the *E. coli* heat-
labile toxins (LT1 and LT2), *Pseudomonas* endotoxin A,
C. botulinum C2 and C3 toxins, as well as toxins from
C. perfringens, *C. spiriforma* and *C. difficile*,
particularly ADP-ribosylating bacterial toxin mutants

25 such as CRM_{197}, a non-toxic diphtheria toxin mutant
(see, e.g., Bixler et al. (1989) *Adv. Exp. Med. Biol.*
$\underline{251}$:175; and Constantino et al. (1992) *Vaccine*);
saponin adjuvants such as Quil A (U.S. Pat. No.
5,057,540), or particles generated from saponins such

30 as ISCOMs (immunostimulating complexes); cytokines,
such as interleukins (e.g., IL-1, IL-2, IL-4, IL-5,
IL-6, IL-7, IL-12, etc.), interferons (e.g., gamma
interferon), macrophage colony stimulating factor (M-
CSF), tumor necrosis factor (TNF), etc; muramyl

35 peptides such as N-acetyl-muramyl-L-threonyl-D-
isoglutamine (thr-MDP), N-acetyl-normuramyl-^{L}-alanyl-^{D}-

isoglutamine (nor-MDP) , N-acetylmuramyl-$^{\text{L}}$-alanyl-$^{\text{D}}$-
isoglutaminyl-$^{\text{L}}$-alanine-2- (1'-2'-dipalmitoyl-*sn*-
glycero-3 huydroxyphosphoryloxy)-ethylamine (MTP-PE) ,
etc.; adjuvants derived from the CpG family of

5   molecules, CpG dinucleotides and synthetic
oligonucleotides which comprise CpG motifs (see, e.g.,
Krieg et al. *Nature* (1995) 374:546 and Davis et al. *J.
Immunol.* (1998) 160:870-876) such as
TCCATGACGTTCCTGATGCT (SEQ ID NO:1) and

10   ATCGACTCTCGAGCGTTCTC (SEQ ID NO:2); and synthetic
adjuvants such as PCPP
(Poly[di(carboxylatophenoxy)phosphazene) (Payne et al.
Vaccines (1998) 16:92-98). Such adjuvants are
commercially available from a number of distributors

15   such as Accurate Chemicals; Ribi Immunechemicals,
Hamilton, MT; GIBCO; Sigma, St. Louis, MO.
              Once obtained, the adjuvant, with or without
the antigen of interest, is formed into a particle
suitable for transdermal delivery using any suitable

20   particle formation technique, such as air-drying
(crystallization) freeze-drying (lyophilization),
spray-coating or supercritical fluid techniques. The
compositions may also be prepared as crystalline
compositions, as described above.

25   Following their formation, the subject
particles are delivered transdermally to mammalian
tissue using a suitable transdermal delivery
technique. Various particle acceleration devices
suitable for transdermal delivery of the substance of

30   interest are known in the art, and will find use in
the practice of the invention. A particularly
preferred transdermal delivery system employs a
needleless syringe to fire solid drug-containing
particles in controlled doses into and through intact

35   skin and tissue. See, e.g., U.S. Patent No. 5,630,796
to Bellhouse et al. which describes a needleless

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syringe (also known as "the PowderJect® needleless syringe device"). Other needleless syringe configurations are known in the art and are described herein.

5   The particles are administered to the subject in a manner compatible with the dosage formulation, and in an amount that will be effective to achieve the desired physiological response. Generally, the response generated will be

10   prophylactically and/or therapeutically effective. Thus, for example, if an antigen or vaccine composition is being delivered, the amount administered will be sufficient to generate an immune response. If an adjuvant is coadministered with the

15   antigen, it will be delivered in an amount sufficient to enhance the immune response to the coadministered antigen. It is readily apparent that the amount of the composition to be delivered depends on the particular substance administered, the subject to be

20   treated and the disease to be prevented or treated.
           Generally about .5 μg to 1000 μg of adjuvant, more generally 1 μg to about 500 μg of adjuvant and most preferably about 5 μg to about 300 μg of adjuvant will be effective to enhance an immune

25   response of a given antigen. Thus, for example, for CpG, doses in the range of about .5 to 50 μg, more preferably 1 to about 25 μg, preferably 5 to about 20 μg, will find use with the present methods. Similarly, for alum or PCPP, a dose of about 25 μg to

30   about 500 μg, preferably about 50 to about 250 μg, and most preferably about 75 to about 150 μg, will find use herein. For MPL, a dose in the range of about 10 to 250 μg, preferably about 20 to 150 μg, and most preferably about 40 to about 75 μg, will find use with

35   the present methods.

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Doses for other adjuvants can readily be determined by one of skill in the art using routine methods. The amount to administer will depend on a number of factors including the coadministered

5   antigen, as well as the ability of the adjuvant to act as an immune stimulator.

Similarly, if an antigen is administered transdermally, either in the same or a different composition, generally 50 ng to 1 mg and more

10   preferably 1 μg to about 50 μg of antigen, will be useful in generating an immune response. The exact amount necessary will vary depending on the age and general condition of the subject to be treated, the severity of the condition being treated and the

15   particular antigen or antigens selected, the site of administration, as well as other factors. An appropriate effective amount can be readily determined by one of skill in the art upon reading the instant specification and through routine trials.

20   Dosage treatment may be a single dose schedule or a multiple dose schedule. For vaccine compositions, a multiple dose schedule is one in which a primary course of vaccination may be with 1-10 separate doses, followed by other doses given at

25   subsequent time intervals, chosen to maintain and/or reinforce the immune response, for example at 1-4 months for a second dose, and if needed, a subsequent dose(s) after several months. The dosage regimen will also, at least in part, be determined by the need of

30   the subject and be dependent on the judgment of the practitioner. Furthermore, if prevention of disease is desired, the compositions are generally administered prior to primary infection with the pathogen of interest. If treatment is desired, e.g.,

35   the reduction of symptoms or recurrences, the

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compositions are generally administered subsequent to
primary infection.

5   C.   Experimental

            Below are examples of specific embodiments
for carrying out the present invention. The examples
are offered for illustrative purposes only, and are
not intended to limit the scope of the present
10   invention in any way.

            Efforts have been made to ensure accuracy
with respect to numbers used (e.g., amounts,
temperatures, etc.), but some experimental error and
deviation should, of course, be allowed for.

15

       C.1   Particle Formulations and Particle Formation
Techniques

                          Example 1
20   Particulate Vaccine Compositions

            The following study was carried out to
assess the effect that various excipients and particle
formation processes have on the physical properties of
25   the resultant particulate vaccine compositions, and
the immunogenicity of such reformulated vaccines.
Diphtheria toxoid (dT), a purified subunit protein
antigen, was selected for formulation with different
excipients including mannitol (plus
30   polyvinylpyrrolidone (PVP)), sucrose, and trehalose.
Two powder processing techniques, freeze-drying and
air-drying (evaporative drying), were also compared.
For each formulation tested, the resulting particulate
composition was classified in the following particle
35   fractions: <20μm, 20-38μm, 38-53μm, and 53-75μm using
3" diameter stainless steel sieves.

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Physical characterization of the particulate
vaccine compositions included an assessment of size
distribution, penetration energy, optical microscopy,
scanning electronic microscopy, absolute density, pore
5   size distribution, surface area analysis, and X-ray
powder diffraction.

To determine immunogenicity of reformulated vaccine
delivered with a needleless syringe device (e.g., a
PowderJect® needleless syringe device) or by
10   conventional syringe/needle injection, Balb/C mice
(female, 6-8 weeks old) were vaccinated on weeks 0 and
4. Mice vaccinated with the PowderJect® needleless
syringe device received 5µg of vaccine formulated with
1 mg of excipient. Control mice were injected
15   intraperitoneally with a conventional needle and
syringe. Two weeks post boost, sera was collected and
pooled from 8 mice, and antibodies to dT were
determined by ELISA.

The result of the physical characterization
20   of the particulate compositions was as follows: (1)
the air-drying process yielded high density crystal
particles, while freeze-drying yielded relatively low-
density amorphous powders; and (2) particle size
distribution appeared to be independent of excipients
25   and the particle formation process used. The
particles were fractionated by sieving into 5 sizes
(<20µm, 20-38µm, 38-53µm, 53-75µm, and >75µm, and the
mass distribution for each fraction is about
equivalent.

30   The results of the immunogenicity assessment
are depicted in Tables 1 and 2 below, and in Figure 1.
As can be seen, immunogenicity between the various
particulate vaccine compositions was very similar
(among all formulations and different size fractions
35   for the same formulation). All of the particulate
compositions delivered by needleless syringe elicited

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higher antibody titers than the control group
(conventional needle and syringe delivery). The
trehalose excipient appeared to perform slightly
better than the other formulations, and the 20-53μm

5   fractions appeared to be more immunogenic (see Figure
1). However, both the <20μm and the >75μm particle
fractions were more immunogenic than the control
(aqueous compositions, conventional needle and syringe
delivery). It can also be seen that needleless

10   syringe (PowderJect®) delivery of the crystalline
vaccine composition particles resulted in a higher
seroconversion rate than the control (conventional
needle and syringe) injection method (see Table 2).
In this regard, 97% (157 out of 162) of animals

15   developed serum antibodies after a single PowderJect®
vaccination, while the seroconversion rate was 37.5%
(3 out of 8) for the control group.

20

25

30

35

Table 1					
IgG Antibodies to dT (Pooled Serum)					
Excipient	Particle Formation Method	Particle Size (μm)	Delivery Method	Prime	Boost
saline	control	-	syringe and needle	1220	111600
trehalose	Air-dry	<20	PJ*	1550	616380
trehalose	Air-dry	20-38	PJ	5460	1390700
trehalose	Air-dry	38-53	PJ	7295	1282100
trehalose	Air-dry	53-75	PJ	2690	577080
trehalose	Air-dry	>75	PJ	2310	620460
trehalose/ mannitol	Freeze-dry	20-38	PJ	1590	441140
trehalose + mannitol	Freeze-dry	38-53	PJ	4590	686540
trehalose + mannitol	Freeze-dry	53-75	PJ	2850	657780
trehalose + mannitol	Freeze-dry	>75	PJ	1940	282630
sucrose	Air-dry	20-38	PJ	4650	1160220
sucrose	Air-dry	38-53	PJ	3040	515760
sucrose	Air-dry	53-75	PJ	1750	372160
sucrose	Air-dry	>75	PJ	5230	759240
sucrose	Freeze-dry	20-38	PJ	1525	618100
sucrose	Freeze-dry	38-53	PJ	2950	614780
sucrose	Freeze-dry	53-75	PJ	7830	802850
sucrose	Freeze-dry	>75	PJ	1800	780710
Mannitol/PVP	Freeze-dry	20-38	PJ	3700	494330
Mannitol/PVP	Freeze-dry	38-53	PJ	2810	609940
Mannitol/PVP	Freeze-dry	53-75	PJ	4580	935700
Mannitol/PVP	Freeze-dry	>75	PJ	1590	447630

*PJ = PowderJect®
Note: Week 0 sera had a titer <200. The dT dose for all vaccination is 5 μg.

Table 2						
Seroconversion Rate						
Excipient	Particle Formulatio n Method	Seroconverted/Total Animals				
		<20	20-38	38-53	53-75	>75
Trehalose	Air-Dry	4/4	7/8	7/8	7/8	8/8
Trehalose + Mannitol	Freeze-Dry	-	8/8	8/8	8/8	7/8
Sucrose	Air-Dry	-	7/8	8/8	7/7	7/7
Sucrose	Freeze-Dry	-	8/8	8/8	8/8	6/8
Mannitol/P VP	Freeze-Dry	-	8/8	7/8	8/8	7/8
DT/injecti on	-	3/8				

C.2   Formation and Assessment of Crystalline Vaccine Compositions

Example 2

Formulation of Crystalline Vaccine Compositions

A number of conventional vaccine compositions were crystallized using the following methods.

Pneumococcus capsular polysaccharide #14 (CP14) was obtained as a lyophilized powder from the ATCC. A volume of 1 ml of Water for Injection was dispensed into a 2 mg vial of CP14, and the resulting suspension was continuously mixed at 4°C overnight as specified by the manufacturer's instructions. 100 μl aliquots of the mixture were made and frozen until needed. A quantity of 99.5 mg trehalose (Sigma) powder was weighed and mixed with defrosted aliquots of the CP14 suspension to provide a 500 μg total of CP14. Approximately 1200 μl of Water for Injection was used to dissolve the CP14/trehalose mixture, and the solution was thoroughly mixed. 100 μl aliquots of the solution were then dispensed onto the surface of weigh boats, and placed in the constant airflow

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provided by a fume hood. The droplets were then dried
evaporatively over the next 1-2 days to form a
crystalline product. The crystals were removed from
the weigh boats and ground lightly using mortar and
5   pestle.

One standard adult vial of Engerix-B® (Smith
Kline Beecham), which contains 20 μg of the HepB
surface antigen adsorbed onto 0.5 mg aluminum
hydroxide (alum) was combined with 10 mg trehalose,
10   and the resulting solution mixed thoroughly. 100 μl
droplets were dispensed onto weigh boats, and
desiccated as described herein above. After
approximately 36 hours of evaporative drying,
crystalline vaccine residues were carefully removed
15   from the weigh boats using a spatula. The crystalline
composition was then ground lightly using mortar and
pestle until the larger crystals had been visibly
reduced in size. 1.25 ± 0.25 mg aliquots were
dispensed into drug cassettes, providing a nominal
20   dose of 2.5 μg of the Hepatitis B surface antigen.

A quantity of Hepatitis B surface antigen
(HbsAg), purified from human plasma, was obtained
(Biodesign International). The HbsAg was combined
with trehalose and dI water solution. The resulting
25   solution was gently mixed, poured into a glass petri
dish and allowed to air-dry for 2 days under a fume
hood. Further drying was carried out for an
additional day in a desiccator (Nalgene Plastic
desiccator) which was purged with N₂ gas. The dried
30   solid composition was collected by scraping and then
comminuted using a mortar and pestle. The resultant
dry powder was weighed, and the amount of dry material
for each dose was determined by dividing the total
weight by the number of doses formulated. Particle
35   size distribution of the formulated HbsAg vaccine
composition varied over a broad range (1-100 μm).

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Typically, each dose required about 1-2 mg of dry
mass, with a weighing variation of about 10% or less.

A quantity HibTITER® (Wyeth Lederle), which
is comprised of a PRP-CRM197 conjugate vaccine

5   composition, was obtained. The composition contains
polyribosyl ribose phosphate (polysaccharide from type
b _Haemophilus influenzae_) conjugated to the CRM197
mutant diphtheria toxin carrier, and is referred to
herein as the "Hib conjugate vaccine composition."

10   The Hib conjugate vaccine composition was combined
with trehalose, and the resulting solution mixed
thoroughly. The solution was then dispensed onto
weigh boats, and desiccated as previously described.
After evaporative drying, crystalline vaccine residues

15   were obtained from the weigh boats, and the
crystalline composition was ground lightly using
mortar and pestle, and appropriate dosages thereof
were measured into cassettes for delivery from a
needleless syringe.

20   A quantity of influenza virus, PR8 strain,
was obtained from Spafas (Storrs, CT). In addition, a
quantity of influenza virus, Aichi strain, was
obtained from Dr. Yoshihero Kawaoka, Veterinary
School, University of Wisconsin (Madison, Wisconsin).

25   Each virus was inactivated by standard formalin
treatment (1:4,000, 48 hours at 4°C). Inactivated
virus (either PR8 or Aichi) was then combined with
trehalose and dI water solution. The resulting
solution was gently mixed, poured into a glass petri

30   dish and allowed to air-dry for 2 days under a fume
hood. Further drying was carried out for an
additional day in a desiccator (Nalgene Plastic
desiccator) which was purged with N_2 gas. The dried
solid composition was collected by scraping and then

35   comminuted using a mortar and pestle. The resultant
dry powder was weighed, and the amount of dry material

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for each dose was determined by dividing the total
weight by the number of doses formulated. Particle
size distribution of the formulated whole-inactivated
virus vaccine composition varied over a broad range

5   (1-100 μm). Typically, each dose required about 1-2
mg of dry mass, with a weighing variation of about 10%
or less.

A quantity of Diphtheria toxoid was obtained
(Accurate Chemical & Scientific Corp., manufactured by

10   Statems Serum Institute, Denmark). The toxoid was
combined with trehalose and dI water solution. The
resulting solution was gently mixed, poured into a
glass petri dish and allowed to air-dry for 2 days
under a fume hood. Further drying was carried out for

15   an additional day in a desiccator (Nalgene Plastic
desiccator) which was purged with N_2 gas. The dried
solid composition was collected by scraping and then
comminuted using a mortar and pestle. The resultant
dry powder was weighed, and the amount of dry material

20   for each dose was determined by dividing the total
weight by the number of doses formulated. Particle
size distribution of the formulated Diphtheria toxoid
vaccine composition varied over a broad range (1-100
μm). Typically, each dose required about 1-2 mg of

25   dry mass, with a weighing variation of about 10% or
less.

Example 3
Vaccination with the Crystalline

30   ### Vaccine Compositions
Devices: Unless otherwise noted, the
needleless syringe delivery devices used in skin
delivery studies (either the PowderJect® ND device
series or Oral PowderJect® device series) were

35   obtained from PowderJect Technologies, Ltd., Oxford,
UK. The PowderJect® ND device is generally described

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in commonly owned U.S. Patent No. 5,630,796. The Oral
PowderJect® device is generally described in commonly
owned International Publication No. WO 96/20022. The
gas cylinders in the devices used herein were
5   typically filled with helium gas between 40 and 60 bar
pressure, although anywhere from 30 to 80 bar pressure
can also be used. In operation, compressed helium in
the gas cylinder is released upon actuation of the
device, rupturing the membranes of the particle-
10   containing payload cassette. A supersonic condition
is created, and the resulting high velocity gas flow
propels the particles as projectiles into the target
tissue surface. Varying the pressure of the helium
gas in the gas cylinder can control the depth of
15   penetration. For conventional needle and syringe
delivery, disposable syringes were fitted with 26.5
gauge needles.

        Mice and vaccination: Female Balb/c mice or
Swiss Webster mice, 7 weeks of age were purchased from
20   an authorized vendor (e.g., HSD) and acclimated for 1
week at a mouse facility before vaccination. Mice
were anesthetized by an intraperitoneal (IP) injection
of 100mg/kg ketamine mixed with10 mg/kg xylazine, and
the abdominal skin at the target site was depilated by
25   shaving. The needleless syringe device was gently
pressed against the vaccination site and abutted. A
typical immunization regime consisted of two
vaccinations, four weeks apart, with blood collection
via retro-orbital bleeding under anesthesia prior to
30   each vaccination and two weeks post boost.

        ELISA: In general, antibody response to the
reformulated vaccines was determined by an ELISA. A
96-well plate was coated with 0.1µg of detecting
antigen in PBS per well overnight at 4°C. The plates
35   were washed 3 times with TBS containing 0.1% Brij-35,
and incubated with test sera diluted in PBS containing

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1% BSA for 1.5 hours. A serum standard, which contains high level of antibodies to specific antigen, was added to each plate and used to standardize the titer in the final data analysis. The plates were then washed and incubated with biotin-labeled goat antibodies specific for mouse immunoglobulin IgG or IgG subclasses (1:8,000 in PBS, Southern Biotechnology) for 1 hr at room temperature. Following three additional washes, the plates were incubated with strepavidin-horseradish peroxidase conjugates (1:8,000 in PBS, Southern Biotechnology) for 1 hr at room temperature. Finally, the plates were washed and developed with a TMB substrate kit (obtained from Bio-Rad, Richmond, CA). Endpoint titers of the test sera were determined using the Softmax Pro 4.1 program (Molecular Devices) as the calibrated highest dilution with an A_{450} that exceeded the mean background by 0.1. Mean background absorbence was determined by wells that received all reagents but test sera.

　　　　　1.　Vaccination with crystalline *pneumococcus* capsular polysaccharide #14 (CP14). Experimental groups of Balb/c mice were randomly formed based on the route of administration (intraperitoneal (IP) or intradermal (ID)), and formulation, as shown in the test matrix of Table 3. The mice were given a prime and a boost four weeks after the prime using the above-described crystalline CP14 vaccine composition, and then bled 10 days after the boost. For the boost, the mice were anesthetized with an injection of a mouse anesthetic to enable retro-orbital bleeding prior to booster administration. For needleless syringe delivery, fur was removed by clipping, and delivery was carried out using 60 bar gaseous pressure from the PowderJect®

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needleless syringe delivery device.   Serum samples are
then analyzed to determine antibody titers to
pneumococcus.

Table 3					
Group #	n	Delivery Route	Pressure (bar)	Formulation	CP dose (μg)
I	3	N/S-IP	---	CP14 + Trehalose with alum	5
II	3	N/S-IP	---	CP14 + Trehalose	5
III	3	N/S-IP	---	CP14 + Alum	5
IV	4	PJ-ID	60	CP14 + Trehalose	5
V	4	PJ-ID	60	CP14 + Trehalose	10
VI	4	PJ-ID	60	CP14	50
VII	2	PJ-ID	60	Trehalose only	0

2.   Vaccination with the crystalline
Hepatitis B (HepB) surface antigen vaccine
composition.   The crystalline HepB vaccine composition
(as described above) was administered (in 2.5 μg
carbohydrate doses) to mice as follows.   Eight Balb/c
mice were divided into two cohorts based on the
vaccine composition and delivery technique used: (1)
intraperitoneal using a needle-syringe to deliver
conventional (liquid) Engerix-B® vaccine composition
(n=2); and (2) intradermal using a PowderJect®
needleless syringe to deliver the crystalline vaccine
composition (n=6).   Delivery pressure from the
PowderJect® device ranged from 40 to 60 bar.   All
animals were boosted three weeks after priming, and
bled 10 days following the boost.

Antibody titers to the Hepatitis B surface
antigen were then determined by ELISA using the blood
samples obtained 10 days post administration of the

boost.   The results are depicted below in Table 4.
Titers greater than about 10 mIU/mL are considered
sero-protective.   As can be seen, 5 out of 6 of the
animals receiving the crystalline composition via
5   needleless syringe were protected by the crystalline
vaccine composition.

Table 4			
Mouse #	Delivery Route	Po (bar)	Comments
1	Needle-syringe (IP)	---	---
2	Needle-syringe (IP)	---	---
3	PowderJect® (ID)	40	Prime: poor delivery
4	PowderJect® (ID)	40	Prime: good
5	PowderJect® (ID)	40	Prime: OK
6	PowderJect® (ID)	60	Prime: OK
7	PowderJect® (ID)	60	Prime: OK
8	PowderJect® (ID)	60	Prime: microbleeds

A subsequent boost using the same
crystalline HepB surface antigen vaccine composition
was sufficient to significantly raise all antibody
titers in the animals receiving the needleless
25   injection (via the PowderJect® device), such that all
6 animals were protected by the crystalline vaccine
composition.

30   3.   Vaccination with the crystalline
Haemophilus influenzae polyribosyl ribose phosphate
conjugate vaccine composition (Hib conjugate).   The
above-described crystalline Hib conjugate vaccine
composition was administered to mice as follows.
Swiss Webster mice were divided into experimental
35   groups based on administration technique, dosage, and

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formulation: (Group 1, 2 μg (PRP carbohydrate) of a
liquid Hib conjugate vaccine composition delivered IP
using conventional needle and syringe, n=3); (Group 2,
2.5 μg (PRP carbohydrate) of the crystalline Hib

5   conjugate vaccine composition delivered to skin using
the PowderJect® needleless syringe, n=6); and (Group
3, control (naive), n=3). All vaccinated animals
received a prime, followed by a boost at 4 weeks after
prime. Serum samples were collected 2 weeks after

10   boost, pooled and antibody titers to immobilized PRP-
CRM197 were determined using ELISA.

          Due to observed differences in binding of
human and mouse anti-Haemophilus polysaccharide (HbPs)
antibodies, the HbO-HA ELISA described by Phipps et

15   al. (1990) *J. Immunol. Methods* 135:121-128, was
adapted for use in testing mouse sera. The assay
conditions adapted for the measurement of mouse anti-
HbPs antibodies are noted in Table 5 below. All other
assay conditions are as described by Phipps et al.

20

Table 5		
	Human	Mouse
Antigen Coating Buffer	PBS	50 mM HEPES
Serum Dilution Buffer	PBS/0.3% Tween 20/0.01M EDTA	50 mM HEPES/0.1% Brij 35/1% FBS
Serum Incubation Time & Temp	60 minutes at room temperature	Overnight @ 4°C
Secondary Antibody Conjugate	anti-human Ig* AP	anti-mouse IgG* AP
Secondary Conjugate Buffer	PBS/0.05% Tween 20	50 mM HEPES/0.1% Brij 35/1% FBS
Wash Buffer	PBS/0.1% Tween 20	50 mM HEPES/0.1% Brij 35

*Evaluation has shown that quantitative antibody values
in mouse sera measured using this ELISA are higher

35   than those measured using a radio-antigen binding
assay (RABA) especially for sera with titers less than
10 μg/mL in the RABA.

The results of the ELISA are depicted below
in Table 6. As can be seen, the crystalline vaccine
composition gave comparable results with the
5 conventional vaccine composition.

Table 6 Immunogenicity of Hib Conjugate in Mice					
Immunogen	Number of Mice	μg X Doses	Mode of Delivery	ELISA Titer to PRP-CRM197 IgG	IgM
PRP-CRM197	3	2 μg X 2	Needle, IP	24,300	<100
PRP-CRM197	6	2.5 μg X 2	Dry Powder, Skin	24,300	<100
None	3	-	Naive	<100	<100

In order to further characterize the immune
response in the animals receiving the Hib conjugate
vaccine composition, the following study was carried
20 out. Three experimental groups of 6 mice each were
assembled as follows: (Group 1, 2 μg dose (PRP
carbohydrate) of the crystalline Hib conjugate vaccine
composition delivered intradermally using the
PowderJect® needleless syringe device); (Group 2, 2 μg
dose (PRP carbohydrate) of a conventional liquid Hib
25 conjugate vaccine composition delivered
intraperitoneally (IP) using needle and syringe); and
(Group 3, control). The animals were primed, and then
boosted four weeks later. Sera collected 2 weeks
after boost were pooled, and serial dilutions were
30 assayed using the above-described ELISA techniques.
In a first ELISA, the PRP-CRM197 conjugate was used as
the capture phase. The results of this first ELISA
are reported below in Table 7, and depicted in Figure
2. As can be seen, the crystalline composition
35

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provided a substantially identical response relative
to the conventional vaccine delivery.

	Dilu-tion	IP*	PJ*	Naive
Table 7 **Vaccine Response**				
1	100	1.09 (0.024)	1.131 (0.012)	0.058 (0.019)
2	300	0.934 (0.053)	0.989 (0.003)	0.02 (0.016)
3	900	0.8015 (0.0445)	0.774 (0.004)	0.02 (0.014)
4	2700	0.449 (0.071)	0.502 (0.002)	0.015 (0.013)
5	8100	0.279 (0.006)	0.277 (0.004)	0.01 (0.001)
6	24300	0.129 (0.0315)	0.115 (0.005)	0.009 (0.001)
7	72900	0.0545 (0.0018)	0.041 (0.001)	0.017 (0.008)
8	218700	0.109 (0.005)	0.062 (0.02)	0.073 (0.021)

* (IP) = intraperitoneal needle & syringe delivery, (PJ) =
PowderJect® needleless syringe delivery.

In order to assess the specificity of the
immune response, a second ELISA was performed using
diphtheria toxoid as the capture phase. In this
regard, CRM197 is a mutant form of the diphtheria
toxoid, but CRM197 is highly cross-reactive. Binding
of antisera to the diphtheria toxin was thus used to
assess response toward the CRM197 carrier protein.
The results are reported below in Table 8, and are
depicted in Figure 3. Again, the crystalline vaccine
composition gave comparable results to the
conventional vaccine composition.

Table 8				
	1	2	3	4
	Dilution	Naive	PJ*	IP*
1	100	0.21	1.856	1.8
2	300	0.102	1.846	1.64
3	900	0.117	1.688	1.616
4	2700	0.084	1.38	1.194
5	8100	0.072	0.931	0.797
6	24300	0.077	0.578	0.512
7	82900	0.072	0.3	0.269
8	248700	0.072	0.165	0.17

* (IP) = intraperitoneal needle & syringe delivery, (PJ) =
PowderJect® needleless syringe delivery.

In order to detect PRP-specific antibody
response, a third ELISA was performed using a PRP-
human serum albumin (PRP-HSA) conjugate as the solid
(capture) phase. Since the mice had not been
immunized with the PRP-HSA conjugate, and had not been
exposed to HSA in other contexts, antibody binding is
due to the presence of anti-PRP antibodies. The
results of this ELISA are reported in Table 9 below,
and depicted in Figure 4. As can be seen, the
crystalline and the conventional (liquid) Hib
conjugate vaccine compositions gave comparable
results.

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Table 9				
	1	2	3	4
	Serum Dilution	Naive	PJ*	IP*
1	200	0.184	1.244	1.649
2	400	0.143	0.731	0.956
3	800	0.113	0.455	0.625
4	1600	0.097	0.259	0.322
5	3200	0.075	0.159	0.171
6	6400	0.064	0.105	0.094
7	12800	0.064	0.078	0.068

* (IP) = intraperitoneal needle & syringe delivery, (PJ) = PowderJect® needleless syringe delivery.

In order to determine antibody responses to descending doses of Hib conjugate vaccine following PowderJect® delivery or conventional needle-syringe injection, the following study was carried out. Swiss Webster mice (female, 6-8 weeks old) were vaccinated twice (prime and boost) with either a liquid Hib conjugate vaccine composition or the crystalline Hib conjugate vaccine composition at 4 week-intervals. Four doses (1µg, 0.2µg, 0.04µg, and 0.01µg per dose) of the Hib conjugate composition were tested. For needleless syringe vaccination, each vaccine dose was formulated with 1 mg of trehalose. Control mice were injected intraperitoneally (IP) with a conventional needle and syringe. Blood samples were collected prior to each vaccination, and 2-weeks post boost. Antibodies to PRP and CRM197 were assayed by ELISA as described above. Sera collected 2 weeks post boost were pooled, and the pooled sera were assayed using the above-described ELISA techniques. The results are depicted in Figure 5. As can be seen, at the 1µg dose, the IgG titers appeared to be comparable between the mice immunized by PowderJect® needleless syringe

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delivery and the mice immunized using conventional
needle and syringe. In the 0.01-0.2μg dose range,
antibody levels in the mice immunized using the
PowderJect® device appeared to be higher than mice in
5   the corresponding needle and syringe delivery groups.
In addition, antibody responses to CRM197 were also
measured in the immunized animals. Dose-dependent
responses were seen in the groups immunized with the
PowderJect® device (see Figure 5). Control mice
10   (those animals which were immunized by conventional
needle and syringe injection) responded to
vaccinations at the higher (1μg and 0.2μg) doses, but
not at the lower doses. These data indicate that
transdermal immunization of particulate vaccine
15   compositions using the PowderJect® needleless syringe
device is more effective than delivery of liquid
vaccine compositions using conventional needle and
syringe injection techniques, especially for
delivering antigens at low doses.
20   In order to assess the duration of immunity
provided by the crystalline Hib conjugate vaccine
composition, the following study was carried out.
Swiss Webster mice (female, 6-8 weeks old) were
vaccinated with two doses (prime and boost) of the Hib
25   conjugate crystalline vaccine composition at 4 week-
intervals. For PowderJect® needleless syringe
vaccinations, 1μg of vaccine was formulated with 1mg
of the trehalose excipient. As controls, mice were
injected IP with 5μg of a liquid Hib conjugate vaccine
30   composition using conventional needle and syringe
delivery techniques. Blood samples were collected
before each vaccination, 2 weeks post boost, and
monthly thereafter. Antibodies specific to PRP and
CRM197 were assayed using the above-described ELISA
35   techniques. The results of the ELISA assays are
depicted in Figures 6A and 6B. As can be seen,

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PowderJect® delivery of 1μg of the crystalline Hib
conjugate vaccine composition generated levels of
serum antibodies to PRP and CRM197 equivalent to that
elicited by 5μg of conjugate administered by
5   conventional needle and syringe injection. Antibodies
peaked two weeks after boost and lasted for 8 months
without significant reduction. The results indicate
that transdermal delivery of the particulate vaccine
composition with the PowderJect® device elicits a
10   long-lasting serum antibody response that is
comparable to conventional needle and syringe delivery
of a liquid vaccine composition.

4.   Vaccination with the crystalline
15   inactivated influenza virus vaccine composition.
In order to determine antibody responses to descending
doses of influenza vaccine following PowderJect®
delivery of a crystalline vaccine composition or
conventional needle and syringe injection of a liquid
20   vaccine composition, the following study was carried
out. Five experimental groups of Balb/c mice (female,
6-8 weeks old) were established in order to assess
five different doses of the above-described
crystalline inactivated influenza virus (Aichi strain)
25   composition. The five groups received vaccinations at
weeks 0, 4 and 10.5 with 25μg, 5μg, 1μg, 0.2μg, or
0.04μg, respectively, of the inactivated influenza
virus. For PowderJect® transdermal administration,
each dose of the vaccine was formulated with 1 mg of
30   trehalose. Five groups of control mice were also
established. These control mice received vaccinations
at weeks 0, 4 and 10.5 with 25μg, 5μg 1μg, 0.2μg, or
0.04μg, respectively, of inactivated influenza virus
in a liquid vaccine composition (administered IP by
35   conventional needle and syringe injection). Two weeks
after the third vaccination, sera from 8 mice were

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collected and pooled, and an ELISA determined
antibodies to influenza virus.

Two weeks post boost, antibody titers in
pooled sera were determined against the Aichi virus
5   using the above-described ELISA techniques. The
results of the ELISA are depicted in Figure 7. As can
be seen, there was a dose dependent antibody response
for both the PowderJect® transdermal delivery of the
crystalline composition and the conventional needle
10   and syringe injection of the liquid composition.
However, at the same doses of vaccine, the PowderJect®
vaccination elicited higher antibody titers than the
needle and syringe injection, indicating that
PowderJect® delivery of a crystalline vaccine to the
15   skin improves vaccine performance.

Pooled sera were also tested for
hemagglutination inhibition activity (HI). The
results of the HI activity assay are depicted below in
Table 10. As can be seen, there were dose-dependent
20   HI titers in the sera from the vaccinated animals. HI
titers from animals receiving PowderJect® delivery and
conventional needle and syringe injection are similar
at the higher vaccine doses (25μg, 5μg and 1μg).
However, at the lower vaccine doses (0.2μg and 0.04μg)
25   HI titers were only elicited in animals receiving the
crystalline composition from the PowderJect® system.

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Table 10		
HI Antibody Titer in Pooled Week 12 Sera		
Influenza Vaccine (µg)	PowderJect® Delivery	Syringe and Needle Injection
25	40	80
5	20	20
1	20	10
0.2	10	-
0.04	10	-

In order to assess protection against a subsequent influenza virus challenge, the vaccinated animals were challenged on week 12 by intranasal instillation of 1 x 10^6 PFU (100X LD_{50}) of a mouse adapted Aichi influenza virus. More particularly, ten days after the final immunization, mice were anesthetized by an intraperitoneal injection of 100mg/kg ketamine mixed with10 mg/kg xylazine. 1 x 10^6 particle forming units (PFUs) of influenza virus in 50 µl of saline was slowly instilled into the opening of nasal cavity. The mice naturally inhaled the liquid. Animals were then allowed to recover. Body weight of the animals was taken prior to challenge and daily post challenge for 14 days. Animals were monitored daily for symptoms and survival. Animals that lost 25% of pre-challenge body weight and became moribund were euthanized by CO_2.

Survival and body weight loss were recorded daily for 14 days after the challenge. All animals lost weight during days 3-7 after challenge. Survivors gained their weight back by day 14. The results of the protection study are depicted below in Table 11. The survival statistics for animals receiving the vaccine compositions containing 25µg and 5µg of the inactivated virus are depicted in Figures

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8A and 8B, respectively. As can be seen, at the 25μg dose, PowderJect® administration of the crystalline composition gave better protection against mortality than the liquid composition when delivered via

5 conventional needle and syringe injection. A correlation between antibody response and survival was seen in that the animals that died had lower antibody titers. At the 5μg dose, PowderJect® administration of the crystalline composition provided partial

10 protection against mortality, compared with no protection in the animals receiving the same dose by conventional needle and syringe injection. Therefore, transdermal delivery of the crystalline composition via the PowderJect® device provided better protection

15 than conventional needle and syringe injection.

Table 11		
Influenza Challenge Experiment		
Influenza Vaccine (μg)	Survival/Total	
	PowderJect®	Syringe & Needle
25	7/8	5/8
5	3/8	0/8
1	0/8	0/8
0.2	0/8	0/8
0.04	0/8	0/8

Note: Mice received 3-vaccinations on weeks 0, 4 and 10, were challenged with 100X LD50 of a homolgous mouse adapted influenza virus on week 12. Data

30 represents protection for 2 weeks post-challenge.

5. Vaccination with the crystalline Diphtheria toxoid (dT) vaccine composition. In order to determine antibody responses to descending doses of dT vaccine following PowderJect® delivery of the

35 crystalline composition, and to compare these antibody

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responses with those attained from conventional needle
and syringe injection, the following study was carried
out. Two experimental groups of Balb/c mice (female,
6-8 weeks old) were established. The animals received

5   vaccinations at weeks 0 and 4 with a liquid dT vaccine
composition (delivered by needle and syringe
injection) or with a crystalline vaccine composition
(delivered by the PowderJect® needleless syringe
device). Two vaccine doses were tested, that is

10   vaccine compositions containing 5µg and 1µg of the dT
toxoid. For PowderJect® vaccination, each dose of
vaccine was formulated with 1 mg of trehalose.
Control mice were injected IP with a conventional
needle and syringe. Two weeks after the final

15   vaccinations, sera were collected and pooled from 8
mice, and antibodies to dT were determined by the
above described ELISA techniques.

The results of the ELISA are depicted below
in Table 12. As can be seen, transdermal delivery of

20   the crystalline composition containing 1µg of dT
resulted in a serum antibody response that was 15-fold
higher than in animals receiving the same dose of a
liquid vaccine composition by conventional needle and
syringe injection. This indicates that particle-

25   mediated skin delivery is an effective way to
administer the dT vaccine. At the 5µg dose, serum
antibody levels in animals receiving the crystalline
composition by the PowderJect® device were similar to
those seen in animals receiving the liquid composition

30   by conventional needle and syringe injection.

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Table 12		
IgG Titer to dT in Pooled Week 6 Sera Determined by ELISA		
dT (μg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
1	8130	570
5	188830	149560

C.3   Formation and Assessment of Particulate
Adjuvant Compositions

Example 4

Formulation of Particulate Adjuvant Compositions

A number of conventional adjuvant
compositions were formulated in particulate (powder)
form pursuant to the methods of the invention. These
and other adjuvants can be readily reformulated as
powders using any number of conventional particle-
forming processes. Suitable excipients for the
adjuvant compositions include trehalose, sucrose,
agarose, mannitol, or a mixture of these and/or other
sugars. Particle formation techniques can include
air-drying, freeze-drying, spray-coating, and
supercritical fluid methods. However, all adjuvant
formulations used in the following experiments were
prepared using the crystallization methods of the
present invention (particularly as described above in
Sections C.1 and C.2) unless expressly noted
otherwise.

The particulate adjuvant compositions were produced
as follows.

A quantity of aluminum hydroxide and
aluminum phosphate adjuvant (``Alum adjuvant'') was
obtained (manufactured by Superfow Biosector a/s,
obtained from Accurate Chemical and Scientific Corp.).
The Alum adjuvant was combined with trehalose and dI
water solution. The resulting solution was gently

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mixed, poured into a glass petri dish and allowed to
air-dry for 2 days under a fume hood. Further drying
was carried out for an additional day in a desiccator
(Nalgene Plastic desiccator) which was purged with N_2

5   gas. The dried solid composition was collected by
scraping and then comminuted using a mortar and
pestle. The resultant dry powder was weighed, and the
amount of dry material for each dose was determined by
dividing the total weight by the number of doses

10   formulated. Particle size distribution of the
formulated Alum adjuvant composition varied over a
broad range (1-100 μm). Typically, each dose required
about 1-2 mg of dry mass, with a weighing variation of
about 10% or less.

15   A quantity of the MPL adjuvant
(monophosphoryl Lipid A purified from *S. minnesota*
R595) was obtained (RIBI ImmunoChem Research, Inc.).
The MPL adjuvant was combined with trehalose and dI
water solution. The resulting solution was gently

20   mixed, poured into a glass petri dish and allowed to
air-dry for 2 days under a fume hood. Further drying
was carried out for an additional day in a desiccator
(Nalgene Plastic desiccator) which was purged with N_2
gas. The dried solid composition was collected by

25   scraping and then comminuted using a mortar and
pestle. The resultant dry powder was weighed, and the
amount of dry material for each dose was determined by
dividing the total weight by the number of doses
formulated. Particle size distribution of the

30   formulated MPL adjuvant composition varied over a
broad range (1-100 μm). Typically, each dose required
about 1-2 mg of dry mass, with a weighing variation of
about 10% or less.
         A quantity of CpG adjuvant (20mer synthetic

35   oligonucleotides, CpG-1: ATCGACTCTCGAGCGTTCTC, SEQ ID
NO. 1 and CpG-2: TCCATGACGTTCCTGATGCT, SEQ ID NO. 2)

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was obtained (GIBCO-BRL). The CpG adjuvant was
combined with trehalose and dI water solution. The
resulting solution was gently mixed, poured into a
glass petri dish and allowed to air-dry for 2 days

5   under a fume hood. Further drying was carried out for
an additional day in a desiccator (Nalgene Plastic
desiccator) which was purged with N_2 gas. The dried
solid composition was collected by scraping and then
comminuted using a mortar and pestle. The resultant

10   dry powder was weighed, and the amount of dry material
for each dose was determined by dividing the total
weight by the number of doses formulated. Particle
size distribution of the formulated CpG adjuvant
composition varied over a broad range (1-100 μm).

15   Typically, each dose required about 1-2 mg of dry
mass, with a weighing variation of about 10% or less.
        A quantity of PCPP adjuvant (a synthetic
polymer- poly[di(carboxylatophenoxy)phosphazene]) was
obtained (Virus Research Institute). The PCPP

20   adjuvant was combined with trehalose and dI water
solution. The resulting solution was gently mixed,
poured into a glass petri dish and allowed to air-dry
for 2 days under a fume hood. Further drying was
carried out for an additional day in a desiccator

25   (Nalgene Plastic desiccator) which was purged with N_2
gas. The dried solid composition was collected by
scraping and then comminuted using a mortar and
pestle. The resultant dry powder was weighed, and the
amount of dry material for each dose was determined by

30   dividing the total weight by the number of doses
formulated. Particle size distribution of the
formulated PCPP adjuvant composition varied over a
broad range (1-100 μm). Typically, each dose required
about 1-2 mg of dry mass, with a weighing variation of

35   about 10% or less.

Example 5
Vaccination with the Particulate
Adjuvant Compositions

The devices used to deliver the particulate
5   compositions (i.e., the PowderJect® needleless syringe
devices) and the control (liquid) compositions (i.e.,
conventional needle and syringe) are as described
above in Example 3. The experimental animals (female
Balb/c mice) were handled as above, vaccine
10   compositions were also delivered as described above,
and the same ELISA techniques as described above were
used in the following studies. The crystalline and
control (liquid) vaccine compositions which were used
in the following studies were the inactivated whole
15   influenza virus (Aichi strain) compositions and the
Diphtheria toxoid compositions described above in
Example 2. Viral challenge studies (in the influenza
studies) with the mouse-adapted Aichi influenza strain
were carried out as described above in Example 3.
20

1.   Vaccination studies with the
particulate Alum adjuvant composition. The
particulate Alum adjuvant composition was used as an
adjuvant with the crystalline inactivated influenza
25   vaccine composition and delivered via the PowderJect®
needleless syringe delivery system. Mice were
vaccinated with 5μg or 1μg of the crystalline
inactivated influenza vaccine composition either with
or without 100 μg of the particulate Alum adjuvant
30   composition. Control animals were vaccinated
subcutaneously ("S/C") with aqueous formulations of
the same vaccine/ adjuvant compositions using a
conventional needle and syringe. After three
vaccinations were carried out (at weeks 0, 4, and
35   10.5), week 12 sera were pooled from 8 mice, and

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antibodies to influenza virus were determined by the
above-described ELISA techniques.

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The results of the ELISA study are reported
in Table 13 below. Following skin delivery of Alum-
adjuvanted influenza vaccine, the serum antibody
response was significantly higher when compared with
animals receiving the same dose of vaccine without the
adjuvant. Serum antibody levels in the animals that
received the particulate compositions via the
PowderJect® device were similar to those from animals
that were vaccinated with the same vaccine/adjuvant
composition using conventional techniques.
Accordingly, the Alum adjuvant can be delivered to the
skin in powder form to enhance the immunogenicity of
an influenza vaccine.

Table 13			
Total IgG Titer in Pooled Week 12 Sera Determined by ELISA			
Aluminum (μg)	Influenza Vaccine (μg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
none	5	6790	1505
none	1	873	804
100	5	27180	19198
100	1	2539	9966

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In order to assess protection against a
subsequent influenza virus challenge, the vaccinated
animals were challenged on week 12 by intranasal
instillation of 1×10^6 PFU (100X LD_{50}) of a mouse
adapted Aichi influenza virus. More particularly, ten
days after the final immunization, mice were
anesthetized by an intraperitoneal injection of
100mg/kg ketamine mixed with10 mg/kg xylazine. 1×10^6
particle forming units (PFUs) of influenza virus in 50
μl of saline was slowly instilled into the opening of
nasal cavity. The mice naturally inhaled the liquid.

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Animals were then allowed to recover. Body weight of
the animals was taken prior to challenge and daily
post challenge. Animals were monitored daily for
symptoms and survival. Animals that lost 25% of pre-
5   challenge body weight and became moribund were
euthanized by CO_2.

Survival and body weight loss were recorded
daily for 14 days after the challenge. These results
are reported below in Table 14 and depicted in Figure
10.   9. As can be seen, the survival rate in mice
receiving the Alum-adjuvanted vaccine was much greater
than that in mice receiving the vaccine alone.
PowderJect® delivery of the particulate Alum-
adjuvanted influenza vaccine composition offered
15   better protection against weight loss than syringe and
needle injection (see Figure 9). Initially, both
groups of mice lost 18% of their body weight, but the
animals receiving the particulate compositions via the
PowderJect® device regained their body weight at a
20   quicker rate than the subcutaneously vaccinated mice,
indicating that transdermal delivery of particulate
immunomodulators to skin is superior to the
conventional needle and syringe delivery
methodologies.

Table 14			
Protection Against Influenza Challenge			
Aluminum (μg)	Influenza Vaccine (μg)	Survived/Total (PowderJect®)	Survived/Total (Syringe/Needle)
none	5	3/8	0/8
none	1	0/8	0/8
100	5	8/8	7/8
100	1	5/7	6/8
-	Naive mice	2/16	

Note: Data is the number of animals survived for 14 days versus
35   the total number of animals challenged.

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The particulate Alum adjuvant composition
was also used as an adjuvant with the crystalline
Diphtheria toxoid (dT) vaccine composition and
delivered via the PowderJect® needleless syringe
5   delivery system. Mice were vaccinated with 5µg or 1µg
of the crystalline dT vaccine composition either with
or without 100 µg of the particulate Alum adjuvant by
transdermal delivery with the PowderJect® device.
Control animals were vaccinated subcutaneously with
10   aqueous formulations of the same vaccine/ adjuvant
composition using a conventional needle and syringe
delivery system. Vaccinations were carried out at
weeks 0 and 4. Week 6 sera were collected and pooled
from 8 mice, and antibodies to dT were determined by
15   the above-described ELISA techniques.

        The results of the ELISA study are reported
below in Table 15. As can be seen, serum antibody
responses in animals receiving the particulate Alum-
adjuvanted dT vaccine composition via the PowderJect®
20   delivery device were significantly higher when
compared with control animals receiving the same dose
of vaccine without adjuvant. These serum antibody
levels were similar to those seen in animals receiving
the liquid vaccine/adjuvant composition by
25   conventional means.

Table 15			
IgG Titer in Pooled Week 6 Sera Determined by ELISA			
Aluminum (µg)	dT (µg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
none	1	8130	570
100	1	58085	142120

        The IgG subclass titers to dT were also
determined by ELISA, the results of which are reported
35   below in Table 16. As can be seen, transdermal
delivery of the particulate Alum-adjuvanted dT vaccine

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composition via the PowderJect® device elicited
primarily an IgG1 response. A similar IgG subclass
distribution was seen following conventional needle
and syringe injection. This indicates that the Alum
5   adjuvant promotes a Th2-type immune response to the
vaccine upon skin delivery. Thus, particulate Alum
adjuvant can be delivered to skin following the
methods of the invention and used to control the type
of immune response to co-administered vaccines.

10

Table 16					
IgG Subclass Distribution in Pooled Week 6 Sera by ELISA					
Aluminum (μg)	dT (μg)	PowderJect®		Syringe/Needle	
		IgG1	IgG2a	IgG1	IgG2a
none	5	140640	2170	114800	745
100	5	249070	810	359320	1145

2.   Vaccination studies with the
20 particulate PCPP adjuvant composition. The
particulate PCPP adjuvant composition was used as an
adjuvant with the crystalline inactivated influenza
vaccine composition and delivered via the PowderJect®
needleless syringe delivery system. Mice were
25 vaccinated with 5μg or 1μg of the crystalline
inactivated influenza vaccine composition either with
or without 100 μg of the particulate PCPP adjuvant
composition. Control animals were vaccinated S/C with
aqueous formulations of the same vaccine/ adjuvant
30 compositions using a conventional needle and syringe.
After three vaccinations were carried out (at weeks 0,
4, and 10.5), week 12 sera were pooled from 8 mice,
and antibodies to influenza virus were determined by
the above-described ELISA techniques. The injection
35 sites were also visually and manually assessed for
signs of toxicity (e.g., granuloma formation).

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Granulomas are a common form of local toxic
effect seen with the administration of many adjuvants.
Subcutaneous injection of the liquid PCPP-adjuvanted
influenza vaccine composition resulted in granuloma
5   formation in the subcutaneous tissue at the injection
site. In contrast, there were no detectable granulomas
following PowderJect® delivery of the particulate
composition based on gross hand and visual
examination.   These data suggest that transdermal
10   delivery of the particulate PCPP adjuvant reduces or
even avoids the toxicity commonly associated with
PCPP.

In order to assess protection against a
subsequent influenza virus challenge, the vaccinated
15   animals were challenged on week 12 by intranasal
instillation of 1×10^6 PFU (100X LD_{50}) of a mouse
adapted Aichi influenza virus.   The challenge was
carried out as described above.   Survival and body
weight loss were recorded daily for 14 days.   The
20   survival rates are shown in Table 17 below, and body
weights are depicted in Figure 10.   As can be seen
from Table 17, delivery of the particulate PCPP
adjuvant with the crystalline influenza vaccine (at
the 5μg dose) significantly increased the survival
25   rate when compared with unadjuvanted vaccine.   Similar
protection was seen with the control (liquid) animals
at the same vaccine dose.   However, as seen in Figure
10, PowderJect® delivery of the particulate PCPP-
adjuvanted influenza vaccine offered better protection
30   against weight loss than subcutaneous injection using
a conventional needle and syringe system.   In this
regard, both groups of mice initially lost about 15%
of their body weight, but PowderJect® vaccinated mice
regained their body weight at a quicker rate than the
35   subcutaneously vaccinated mice.   No significant
protection was seen in the animals receiving the 1μg

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dose of the influenza vaccine (with or without
adjuvantation), when delivered in either the
particulate or liquid form.

5   The particulate PCPP adjuvant composition
was also used as an adjuvant with the crystalline
Diphtheria toxoid (dT) vaccine composition and
delivered via the PowderJect® needleless syringe
delivery system. Mice were vaccinated with 5µg or 1µg
of the crystalline dT vaccine composition either with
10 or without 100 µg of the particulate PCPP adjuvant by
transdermal delivery with the PowderJect® device.
Control animals were vaccinated subcutaneously with
aqueous formulations of the same vaccine/ adjuvant
composition using a conventional needle and syringe
15 delivery system. Vaccinations were carried out at
weeks 0 and 4. Week 6 sera were collected and pooled
from 8 mice, and antibodies to dT were determined by
the above-described ELISA techniques.

         The results of the ELISA study are reported
20 below in Table 18. As can be seen, serum antibody
responses in animals receiving the particulate PCPP-
adjuvanted dT vaccine composition via the PowderJect®
delivery device were significantly higher when
compared with control animals receiving the same dose
25 of vaccine without adjuvant. These serum antibody
levels were similar to those seen in animals receiving
the liquid vaccine/adjuvant composition by
conventional means.

30

35

Table 17			
Protection Against Influenza Challenge			
PCPP (µg)	Influenza Vaccine (µg)	Survived/Total (PowderJect®)	Survived/Total (Syringe/Needle)
none	5	3/8	0/8
none	1	0/8	0/8
100	5	6/8	7/7
100	1	2/8	2/8
–	Naive mice	2/16	

Note: Data is the number of animals survived for 14 days versus the total number of animals challenged.

Table 18			
IgG Titer in Pooled Week 6 Sera Determined by ELISA			
PCPP (µg)	dT (µg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
none	1	8130	570
100	1	248550	284415

The IgG subclass titers to dT were also determined by ELISA, the results of which are reported below in Table 19. As can be seen, transdermal delivery of the particulate PCPP-adjuvanted dT vaccine composition via the PowderJect® device elicited primarily an IgG1 response. A similar IgG subclass distribution was seen following conventional needle and syringe injection. This indicates that the PCPP adjuvant promotes a Th2-type immune response to the vaccine upon skin delivery. Thus, particulate Alum adjuvant can be delivered to skin following the methods of the invention and used to control the type of immune response to co-administered vaccines.

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Table 19					
IgG Subclass Distribution in Pooled Week 6 Sera by ELISA					
PCPP (μg) dT (μg)	PowderJect®		Syringe/Needle		
		IgG1	IgG2a	IgG1	IgG2a
none	5	140640	2170	114800	745
100	5	308160	3620	585810	3225

3.   Vaccination studies with the particulate CpG adjuvant composition. The particulate CpG adjuvant composition was used as an adjuvant with the crystalline inactivated influenza vaccine composition and delivered via the PowderJect® needleless syringe delivery system. Mice were vaccinated with 5μg or 1μg of the crystalline inactivated influenza vaccine composition either with or without 100 μg of the particulate CpG adjuvant composition. Control animals were vaccinated S/C with aqueous formulations of the same vaccine/ adjuvant compositions using a conventional needle and syringe. After three vaccinations were carried out (at weeks 0, 4, and 10.5), week 12 sera were pooled from 8 mice, and antibodies to influenza virus were determined by the above-described ELISA techniques.

The results of the ELISA study are reported in Table 20 below. Following delivery of the particulate CpG-adjuvanted influenza vaccine via the PowderJect® device, serum antibody responses were significantly higher when compared with animals receiving the same dose of vaccine without the adjuvant. In addition, serum antibody levels in the animals that received the particulate compositions via the PowderJect® device were significantly higher than serum antibody levels in animals vaccinated with the same vaccine/adjuvant composition (in liquid form) using conventional techniques. Accordingly, the CpG adjuvant can be delivered to the skin in powder form

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to enhance the immunogenicity of an influenza vaccine. Delivery in this manner significantly improves the immune enhancement effect provided by the CpG adjuvant.

Table 20			
Total IgG Titer in Pooled Week 12 Sera Determined by ELISA			
CpG (μg)	Influenza Vaccine (μg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
none	5	6790	1505
none	1	873	804
10 μg	5	6066	874
10 μg	1	2862	<100

        IgG subclass titers to the influenza virus were also determined by ELISA. The results are reported below in Table 21. As can be seen, PowderJect® delivery of the unadjuvanted particulate influenza vaccine composition elicited primarily an IgG1 response. A similar IgG subclass distribution was seen following conventional needle and syringe injection of the liquid vaccine composition, except that the titer was much lower by this route. These data indicate that influenza vaccine by itself elicits a Th2- type of immunity. PowderJect® delivery of the particulate CpG-adjuvanted influenza vaccine composition elicited primarily IgG2a antibodies, indicating that CpG promotes Th1 response. Thus, skin is a superior site to deliver CpG adjuvant or CpG adjuvanted vaccines.

Table 21					
IgG Subclass Distribution in Pooled Week 6 Sera by ELISA					
CpG (μg)	Influenza (μg)	PowderJect®		Syringe & Needle	
		IgG1	IgG2a	IgG1	IgG2a
none	1	367	<200	<200	<200
10	1	<200	1858	<200	<200
none	5	16340	<200	<200	<200
10	5	714	8711	<200	547

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In order to assess protection against a
subsequent influenza virus challenge, the vaccinated
animals were challenged on week 12 by intranasal
instillation of 1 x 10^6 PFU (100X LD$_{50}$) of a mouse
5   adapted Aichi influenza virus. The viral challenge
was carried out as described above. Survival and body
weight loss were recorded daily for 14 days. The
survival rates are reported in Table 22.   Body weight
data are depicted in Figures 11A and 11B. As can be
10 seen from Table 22, a 100% survival rate was seen with
animals receiving the particulate vaccine compositions
(at both the 1μg and 5μg doses) when adjuvanted with
CpG and delivered transdermally via the PowderJect®
device. In contrast, subcutaneous injection with the
15 liquid composition did not result in any protection
with at the 1μg dose. Therefore, PowderJect® delivery
of the particulate CpG-adjuvanted influenza vaccine to
the skin is more effective than subcutaneous
injection.
20

Table 22			
Protection Against Influenza Challenge			
CpG (μg)	Influenza Vaccine (μg)	Survived/Total (PowderJect®)	Survived/Total (Syringe/Needle)
none	5	3/8	0/8
none	1	0/8	0/8
10	5	7/7	7/8
10	1	8/8	3/8
-	Naive mice	2/16	

30
Note: Data is the number of animals survived for 14 days versus
the total number of animals challenged.

Referring now to Figures 11A and 11B,
PowderJect® delivery of the particulate CpG-adjuvanted
influenza vaccine composition also offered
35 significantly better protection against weight loss

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than subcutaneous injection of the same vaccine composition using conventional needle and syringe delivery.   In this regard, there was less than a 10% initial weight loss seen in mice vaccinated with

5   either 1μg or 5μg of the crystalline influenza vaccine adjuvanted with CpG, and these mice regained their body weight quickly.   In contrast, subcutaneous injection offered much less protection.   Specifically, there was nearly a 20% initial weight loss in mice

10   subcutaneously injected with the liquid CpG-adjuvanted vaccine (at the 5 μg dose), and weight recovery took significantly longer.   Subcutaneous injection of the liquid CpG-adjuvanted vaccine (at the 1 μg dose) did not offer any protection.   All animals in this control

15   group lost about 25% of their body weight by day 5 and died by day 7.   These data suggest that CpG is a much more effective and potent immunomodulator when delivered to the skin using the PowderJect® system.

         The particulate CpG adjuvant composition was

20   also used as an adjuvant with the crystalline Diphtheria toxoid (dT) vaccine composition and delivered via the PowderJect® needleless syringe delivery system.   Mice were vaccinated with 5μg or 1μg of the crystalline dT vaccine composition either with

25   or without 10 μg of the particulate CpG adjuvant by transdermal delivery with the PowderJect® device. Control animals were vaccinated subcutaneously with aqueous formulations of the same vaccine/ adjuvant composition using a conventional needle and syringe

30   delivery system.   Vaccinations were carried out at weeks 0 and 4.   Week 6 sera were collected and pooled from 8 mice, and antibodies to dT were determined by the above-described ELISA techniques.

         The results of the ELISA study are reported

35   below in Table 23.   As can be seen, serum antibody responses in animals receiving the particulate CpG-

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adjuvanted dT vaccine composition via the PowderJect®
delivery device were significantly higher when
compared with control animals receiving the same dose
of vaccine without adjuvant Serum antibody levels in
5   the animals receiving the particulate compositions via
the PowderJect® delivery device were greater than ten-
fold higher than titers in animals vaccinated with the
same vaccine/adjuvant composition (in liquid form) via
conventional needle and syringe. Thus, delivery of
10 CpG in particulate form enhances the immunogenicity of
the co-administered dT vaccine composition.

Table 23			
IgG Titer in Pooled Week 6 Sera Determined by ELISA			
CpG (μg)	dT (μg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
none	1	8130	570
10	1	614470	33680
none	5	188830	149560
10	5	1483450	116660

IgG subclass titers to the dT antigen were
also determined by ELISA. The results are reported
below in Table 24. As can be seen, PowderJect®
25 delivery of the unadjuvanted particulate influenza
vaccine composition elicited primarily an IgG1
response. A similar IgG subclass distribution was
seen following conventional needle and syringe
injection of the liquid vaccine composition, except
30 that the titer was much lower by this route. These
data indicate that influenza vaccine by itself elicits
a Th2- type of immunity. PowderJect® delivery of the
particulate CpG-adjuvanted influenza vaccine
composition elicited primarily IgG2a antibodies,
35 indicating that CpG promotes Th1 response. A similar
IgG subclass distribution was seen following

conventional needle and syringe injection of the same vaccine composition (but in liquid form), except that the titer was ten-fold lower by this route. Thus, skin is a superior site to deliver CpG adjuvant or CpG adjuvanted vaccines.

Table 24				
IgG Subclass Distribution in Pooled Week 6 Sera by ELISA				
CpG (μg)	dT (μg)	Delivery	IgG Subclass Titer	
			IgG1	IgG2a
none	1	SC	7625	<200
none	1	PJ	605	<200
10	1	SC	297600	14165
10	1	PJ	41850	2350
none	5	SC	140640	2170
none	5	PJ	114800	745
10	5	SC	41050	140200
10	5	PJ	166130	4000

SC = subcutaneous injection, PJ = PowderJect® device.
Vaccinations were given on weeks 0 and 4.

4.   Vaccination studies with liquid and particulate MPL adjuvant compositions. In a first study, a liquid MPL adjuvant composition was used as an adjuvant in combination with the crystalline inactivated influenza vaccine composition (delivered via the PowderJect® needleless syringe delivery device). Mice were vaccinated with 5μg or 1μg of the crystalline inactivated influenza vaccine composition either with or without 50 μg of the liquid MPL adjuvant composition. When MPL adjuvant was used, the liquid MPL composition was injected intradermally using a 27 gauge needle, and the crystalline vaccine was administered 5 minutes later to the same site using the PowderJect® device. Control animals were

vaccinated S/C with aqueous formulations of the same
vaccine/ adjuvant compositions using a conventional
needle and syringe. After three vaccinations were
carried out (at weeks 0, 4, and 10.5), week 12 sera

5   were pooled from 8 mice, and antibodies to influenza
virus were determined by the above-described ELISA
techniques.

The results of the ELISA study are reported
in Table 25 below. Following skin delivery of the

10   MPL-adjuvanted influenza vaccine, the serum antibody
response was significantly higher when compared with
animals receiving the same dose of vaccine without the
adjuvant. Serum antibody levels in the animals that
received the particulate compositions via the

15   PowderJect® device were similar to those from animals
that were vaccinated with the same vaccine/adjuvant
composition using conventional techniques.
Accordingly, the MPL adjuvant can be delivered to the
skin in powder form to enhance the immunogenicity of

20   an influenza vaccine.

Table 25			
Total IgG Titer in Pooled Week 12 Sera Determined by ELISA			
MPL (μg)	Influenza Vaccine (μg)	Serum IgG Titer (PowderJect®)	Serum IgG Titer (Syringe/Needle)
none	5	6790	1505
none	1	873	804
50	5	20042	10089
50	1	1158	2490

Note: Vaccinations were given on weeks 0, 4 and 10.5. MPL was
injected intradermally using a 27 gauge needle, 5 minutes later
vaccine powder was administered to the same site using a
PowderJect® device.

IgG subclass titers to the influenza virus

35   were also determined by ELISA. The results are
reported below in Table 26. As can be seen,

PowderJect® delivery of the unadjuvanted particulate
influenza vaccine composition elicited primarily an
IgG1 response. A similar IgG subclass distribution
was seen following conventional needle and syringe
5   injection of the liquid vaccine composition. The
combination of intradermal MPL adjuvant and
PowderJect® delivery of the crystalline influenza
vaccine composition elicited both IgG1 and IgG2a
antibodies, indicating that skin delivery of MPL
10   induces a balanced Th1/Th2 response to the influenza
vaccine. A similar IgG subclass distribution was seen
following conventional needle and syringe injection of
the liquid vaccine composition.

15

Table 26					
IgG Subclass Distribution in Pooled Week 6 Sera by ELISA					
MPL	Influenza	PowderJect®		Syringe & Needle	
(μg)	(μg)	IgG1	IgG2a	IgG1	IgG2a
none	5	16340	<200	<200	<200
50	5	18985	1848	9548	3700

20

In order to assess protection against a
subsequent influenza virus challenge, the vaccinated
animals were challenged on week 12 by intranasal
25   instillation of 1 x 10^6 PFU (100X LD_{50}) of a mouse
adapted Aichi influenza virus. The challenge was
carried out as described above. Survival and body
weight loss were recorded daily for 14 days. The
survival rates are shown in Table 27 below, and body
30   weight data are depicted in Figure 12. As can be seen
from Table 27, 100% survival was seen in animals
vaccinated with 5 μg of the crystalline vaccine
composition (delivered via PowderJect® device)
adjuvanted with 50 μg of MPL (delivered via
35   intradermal needle and syringe injection), while only
4 of 6 animals survived in the control (delivery via

conventional needle and syringe) group receiving the
same doses of vaccine and adjuvant.   Partial
protection was seen in animals receiving 1 μg of the
vaccine composition with 50 μg MPL by both PowderJect®
5   and conventional needle and syringe delivery.

Table 27			
Protection Against Influenza Challenge			
MPL (μg)	Influenza Vaccine (μg)	Survived/Total (PowderJect®)	Survived/Total (Syringe/Needle)
none	5	3/8	0/8
none	1	0/8	0/8
50	5	7/7	4/6
50	1	3/8	5/8
-	Naive mice	2/16	

Note: Data is the number of animals survived for 14 days versus
the total number of animals after challenge with 10^6 PFUs of
virus.

Referring now to Figure 12, PowderJect®
20   delivery of the crystalline influenza vaccine
composition 9at the 5 μg dose) coupled with the MPL
adjuvant offered significantly better protection
against weight loss than subcutaneous injection of the
same vaccine/adjuvant combination using conventional
25   needle and syringe delivery.   There was maximal weight
loss of 10% in animals receiving the 5μg vaccine dose
(via transdermal PowderJect® delivery) with 50μg of
the MPL adjuvant, however, these animals quickly
regained their weight.   In contrast, animals
30   vaccinated with the liquid composition (S/C) lost
nearly 20% of their body weight, and their weight
recovery progressed at a much slower rate.
In a second study a particulate MPL
composition was used as an adjuvant with the
35   crystalline Diphtheria toxoid (dT) vaccine composition
and delivered via the PowderJect® needleless syringe

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delivery system. Mice were vaccinated with 5μg or 1μg
of the crystalline dT vaccine composition either with
or without 50 μg of the particulate MPL adjuvant
composition by transdermal delivery with the

5   PowderJect® device. Control animals were vaccinated
subcutaneously with aqueous formulations of the same
vaccine/ adjuvant composition using a conventional
needle and syringe delivery system. Vaccinations were
carried out at weeks 0 and 4. Week 6 sera were

10   collected and pooled from 8 mice, and antibodies to dT
were determined by the above-described ELISA
techniques.

         Following transdermal delivery of the
particulate MPL-adjuvanted dT vaccine composition,

15   serum antibody responses were marginally higher when
compared with control animals receiving the same dose
of vaccine without MPL. The level of the serum
antibodies in the animals vaccinated via transdermal
PowderJect® delivery was similar to titers from

20   animals vaccinated with the same vaccine/adjuvant
composition by conventional needle and syringe
injection.

         IgG subclass titers to dT were determined by
ELISA. The results are reported in Table 28. As can

25   be seen, PowderJect® delivery of unadjuvanted dT
vaccine primarily elicited an IgG1 response. A
similar IgG subclass distribution was seen following
needle and syringe injection. The MPL-adjuvanted dT
vaccine composition elicited both IgG1 and IgG2a

30   antibodies when delivered in particulate form from the
PowderJect® device. A similar IgG subclass
distribution was seen following needle and syringe
injection, indicating that PowderJect® delivery of MPL
to the skin can be used to induce a balanced Th1/ Th2-

35   type of immunity.

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Table 28				
IgG Subclass Distribution in Pooled Week 6 Sera by ELISA				
MPL (μg)	dT (μg)	Delivery	IgG Subclass Titer	
			IgG1	IgG2a
none	5	SC	140640	2170
none	5	PJ	114800	745
50	5	SC	258390	10150
50	5	PJ	353300	2925

Mouse strain = Balb/C, SC = subcutaneous injection, PJ = PowderJect® device. Vaccinations were given on weeks 0 and 4.

Accordingly, novel methods for delivering vaccines and adjuvant compositions transdermally are disclosed. Additionally described are novel processed (crystalline) pharmaceutical compositions, and methods for making and using the same. Although preferred embodiments of the subject invention have been described in some detail, it is understood that obvious variations can be made without departing from the spirit and the scope of the invention as defined by the appended claims.

We claim:

1.   A method for enhancing the
immunogenicity of a selected antigen, said method
5   comprising:
(a) administering an effective amount of the
antigen to a vertebrate subject; and
(b) administering an amount of a particulate
adjuvant composition sufficient to enhance the
10   immunogenicity of the antigen, wherein the adjuvant is
delivered into or across skin or tissue of the
vertebrate subject and further wherein said
administering is carried out using a transdermal
delivery technique.

15

2.   The method of claim 1, wherein the
antigen is in particulate form and is delivered into
or across skin or tissue of the vertebrate subject
using a transdermal delivery technique.

20

3.   The method of claim 1, wherein the
particulate adjuvant composition is administered using
a needleless syringe delivery device.

25   4.   The method of claim 1, wherein the
antigen and adjuvant are present in separate
compositions.

5.   The method of claim 1, wherein the
30   antigen and adjuvant are present in the same
composition.

6.   The method of claim 1, wherein the
antigen and adjuvant are administered to different
35   sites in the vertebrate subject.

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7.   The method of claim 1, wherein the antigen and adjuvant are administered to the same site in the vertebrate subject.

5   8.   The method of claim 1, wherein the antigen is administered prior to the adjuvant composition.

9.   The method of claim 1, wherein the
10   antigen is administered subsequent to the adjuvant composition.

10.   The method of claim 1, wherein the antigen is administered concurrently with the adjuvant
15   composition.

11.   The method of claim 1, wherein antigen is   a viral antigen.

20   12.   The method of claim 11, wherein the viral antigen is a viral protein.

13.   The method of claim 11, wherein the viral antigen is a viral particle.
25

14.   The method of claim 1, wherein the antigen is in a subunit vaccine composition.

15.   The method of claim 1, wherein the
30   antigen is a bacterial antigen.

16.   The method of claim 15, wherein the bacterial antigen is a bacterial protein or polysaccharide.
35

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17. The method of claim 1, wherein the antigen is a live, attenuated organism.

18. The method of claim 17, wherein the attenuated organism is a virus.

19. The method of claim 17, wherein the attenuated organism is a bacterium.

20. The method of claim 1, wherein the particulate adjuvant composition is provided in a crystalline form suitable for transdermal delivery.

21. The method of claim 1, wherein the adjuvant is a CpG oligonucleotide.

22. The method of claim 21, wherein the CpG oligonucleotide comprises the sequence TCCATGACGTTCCTGATGCT (SEQ ID NO:1).

23. The method of claim 21, wherein the CpG oligonucleotide comprises the sequence ATCGACTCTCGAGCGTTCTC (SEQ ID NO:2).

24. A method for eliciting an immune response in a vertebrate subject, said method comprising transdermally delivering a particulate vaccine composition into or across skin or tissue of the vertebrate subject, wherein the particulate vaccine composition comprises:
          (a) an effective amount of a selected antigen; and
          (b) an amount of an adjuvant sufficient to enhance the immunogenicity of the antigen.

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25. The method of claim 24, wherein the particulate vaccine composition is administered using a needleless syringe delivery device.

5   26. The method of claim 24, wherein the antigen is a viral antigen.

27. The method of claim 26, wherein the viral antigen is a viral protein.

10

28. The method of claim 26, wherein the viral antigen is a viral particle.

29. The method of claim 24, wherein the

15   vaccine composition is a subunit vaccine composition.

30. The method of claim 24, wherein the antigen is a bacterial antigen.

20   31. The method of claim 30, wherein the bacterial antigen is a bacterial protein or polysaccharide.

32. The method of claim 24, wherein the

25   antigen is a live, attenuated organism.

33. The method of claim 32, wherein the attenuated organism is a virus.

30   34. The method of claim 32, wherein the attenuated organism is a bacterium.

35. The method of claim 24, wherein the particulate vaccine composition is provided in a

35   crystalline form suitable for transdermal delivery.

36.   The method of claim 24, wherein the adjuvant is a CpG oligonucleotide.

37.   The method of claim 36, wherein the CpG oligonucleotide comprises the sequence TCCATGACGTTCCTGATGCT (SEQ ID NO:1).

38.   The method of claim 36, wherein the CpG oligonucleotide comprises the sequence ATCGACTCTCGAGCGTTCTC (SEQ ID NO:2).

39.   A particulate adjuvant composition suitable for delivery into or across skin or tissue of a vertebrate subject using a transdermal delivery technique.

40.   Use of an adjuvant in the manufacture of a particulate composition for transdermal delivery into or across skin or tissue of a vertebrate subject.

41.   The use according to claim 40, wherein the particulate composition comprises a selected antigen and the adjuvant enhances the immunogenicity of the antigen.

42.   The use according to claim 40, wherein the particulate composition is delivered into or across skin or tissue of the vertebrate subject using a needleless syringe delivery device.

43.   The use according to claim 40, wherein antigen is a viral antigen.

44.   The use according to claim 43, wherein the viral antigen is a viral protein.

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45.   The use according to claim 43, wherein the viral antigen is a viral particle.

46.   The use according to claim 40, wherein
5   the antigen is in a subunit vaccine composition.

47.   The use according to claim 40, wherein the antigen is a bacterial antigen.

48.   The use according to claim 47, wherein
10   the bacterial antigen is a bacterial protein or polysaccharide.

49.   The use according to claim 40, wherein
15   the antigen is a live, attenuated organism.

50.   The use according to claim 49, wherein the attenuated organism is a virus.

51.   The use according to claim 49, wherein
20   the attenuated organism is a bacterium.

52.   The use according to claim 40, wherein the particulate composition is provided in a
25   crystalline form suitable for transdermal delivery.

53.   The use according to claim 40, wherein the adjuvant is a CpG oligonucleotide.

54.   The use according to claim 53, wherein
30   the CpG oligonucleotide comprises the sequence TCCATGACGTTCCTGATGCT (SEQ ID NO:1).

55.   The use according to claim 53, wherein
35   the CpG oligonucleotide comprises the sequence ATCGACTCTCGAGCGTTCTC (SEQ ID NO:2).

56. A method of eliciting a physiological effect in a vertebrate subject comprising administering an amount of the particulate adjuvant composition of claim 39 into or across skin or tissue

5   of the vertebrate subject sufficient to bring about the physiological effect.

57. A method for forming a crystalline pharmaceutical composition, said method comprising:

10   (a) combining a liquid pharmaceutical formulation with a suitable pharmaceutical grade sugar to provide a composition;

         (b) allowing the composition to dry under suitable evaporative conditions which favor crystal

15   formation, thereby obtaining a crystalline composition having enhanced density characteristics; and

         (c) collecting the crystalline composition.

58. The method of claim 57, wherein the

20   pharmaceutical composition is a vaccine composition.

59. A crystalline pharmaceutical composition suitable for delivery into or across skin or tissue of a vertebrate subject.

25

60. The composition of claim 59, wherein said composition is a vaccine composition.

61. The composition of claim 60, wherein

30   said composition comprises an antigen and an excipient in an amount sufficient to enhance the density of the crystalline pharmaceutical composition.

62. The composition of claim 61, wherein

35   the antigen is a viral antigen.

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63. The composition of claim 61, wherein the antigen is a bacterial antigen.

64. A method for treating a subject, said method comprising delivering the crystalline pharmaceutical composition of claim 59 into or across skin or tissue of said subject, wherein the crystalline composition is delivered in an amount sufficient to bring about a prophylactic or therapeutic effect in the subject.

65. The method of claim 64, wherein the pharmaceutical composition is a vaccine composition comprising an antigen of interest.

66. The method of claim 65, wherein the vaccine composition is a subunit vaccine composition.

67. The method of claim 65, wherein the vaccine composition comprises a viral antigen.

68. The method of claim 65, wherein the vaccine composition comprises a bacterial antigen.

69. The method of claim 64, wherein the crystalline composition is delivered to the subject using a needleless syringe.

70. Use of a pharmaceutical agent in the manufacture of a crystalline composition for transdermal delivery into or across skin or tissue of a vertebrate subject.

FIG. 1A

FIG. 1B

IgG antibodies to carrier protein

FIG. 2

IgG antibodies to HibTITER vaccine

FIG. 3

IgG antibodies to the Hib polysaccharide
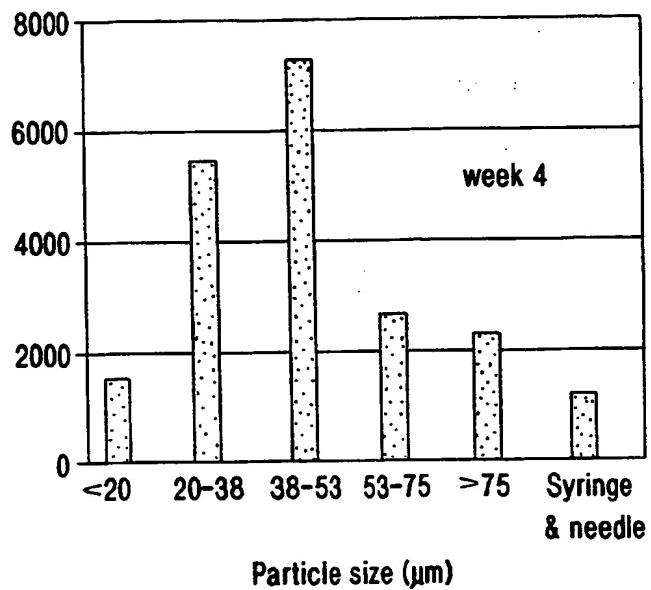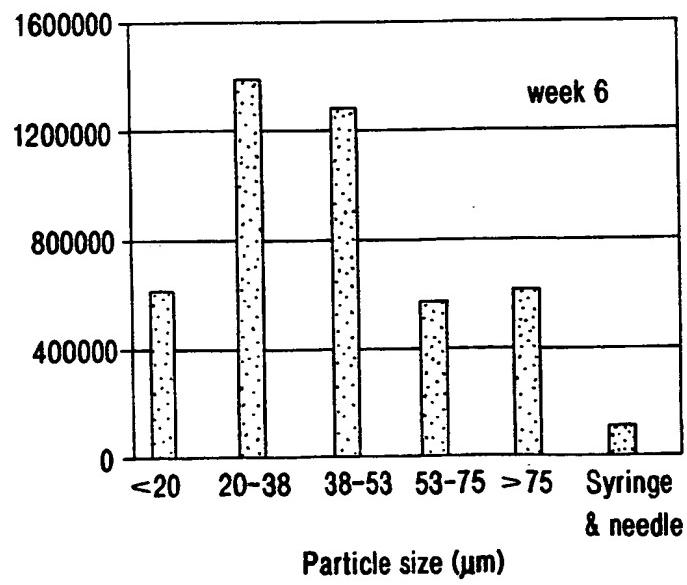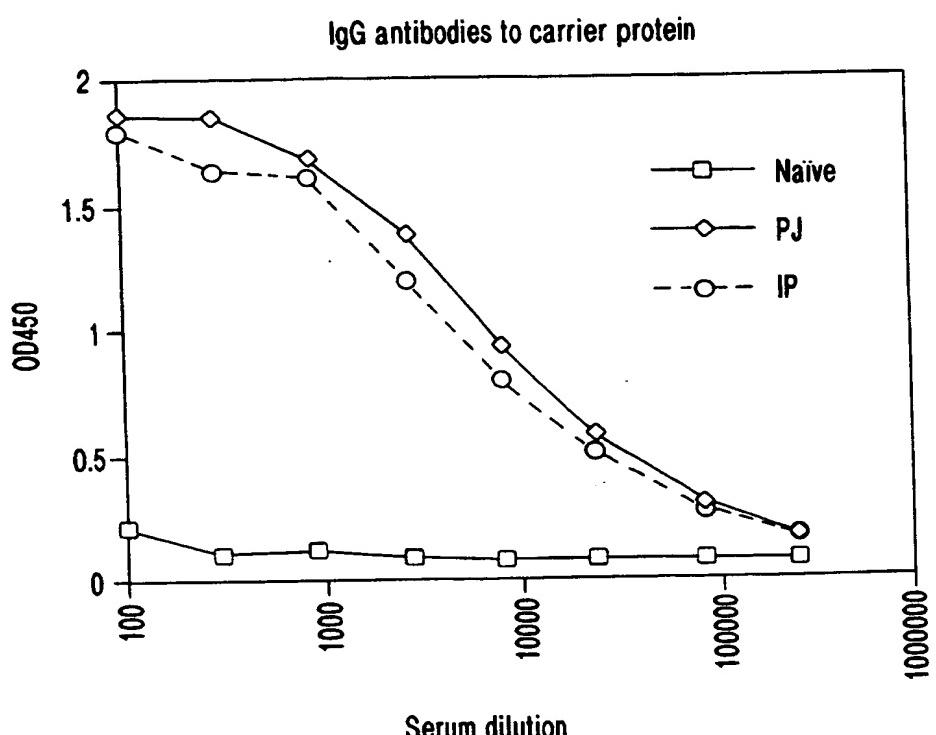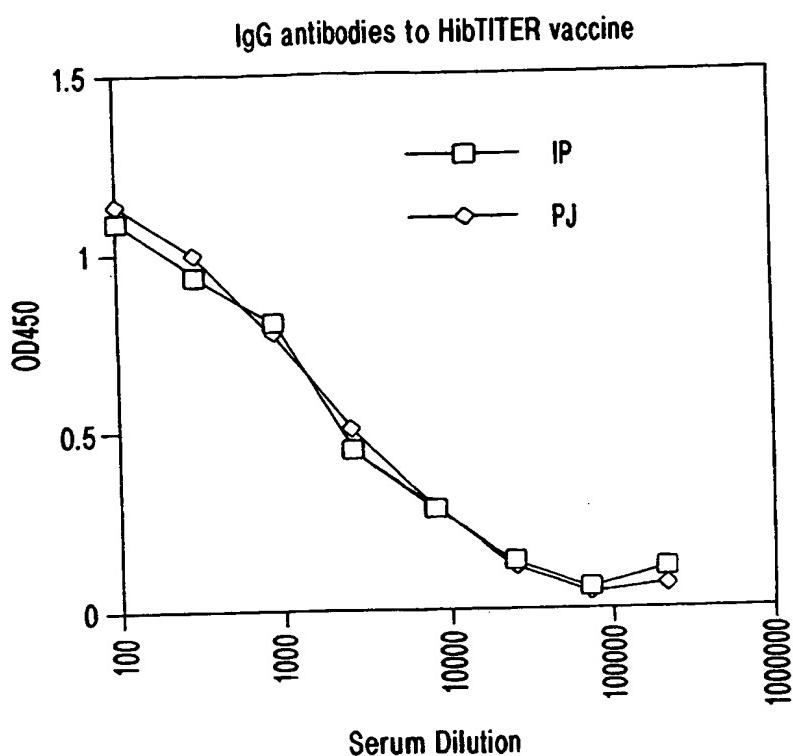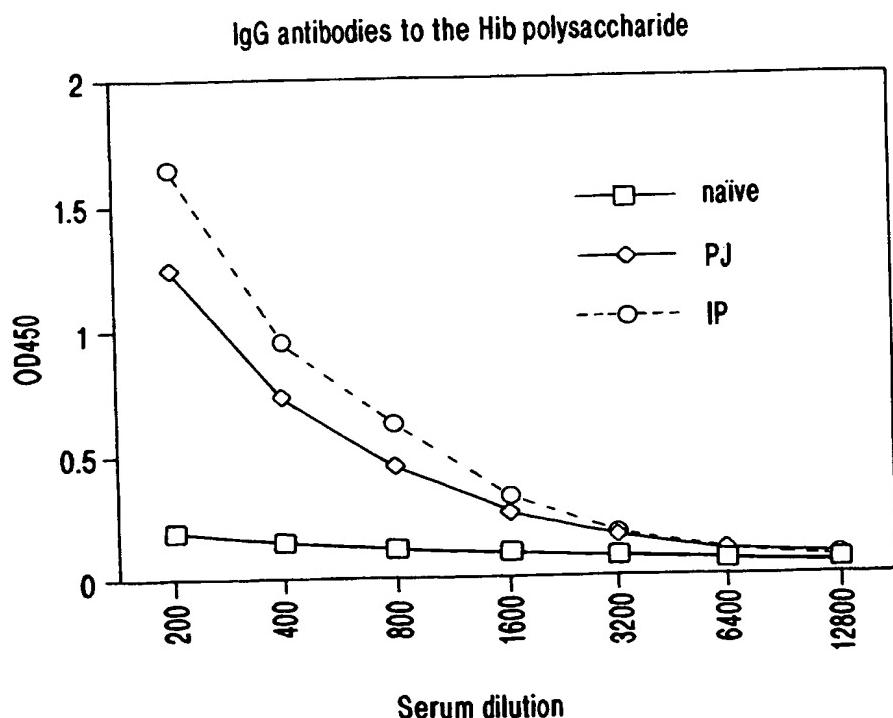
FIG. 4

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FIG. 5

Months post-vaccination

FIG. 6A

Months post-vaccination
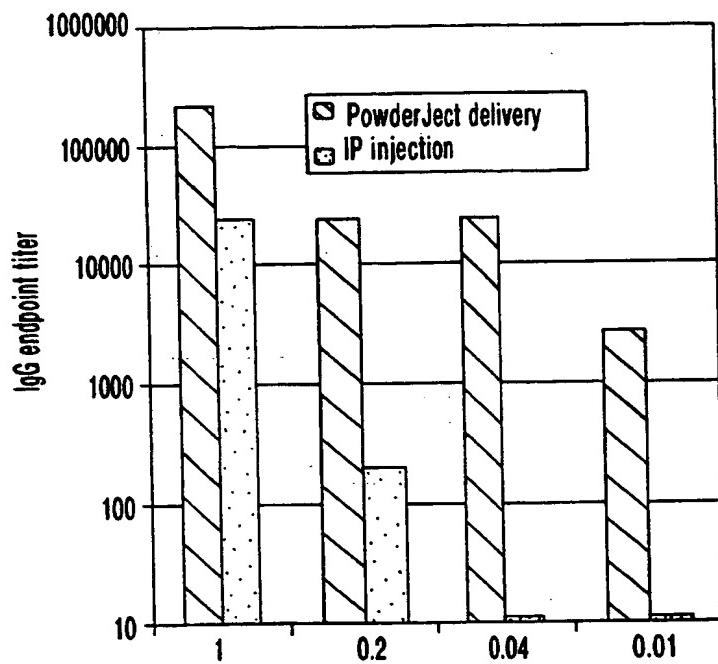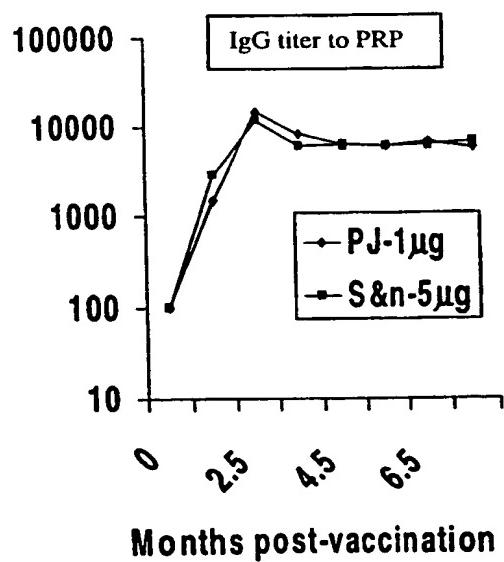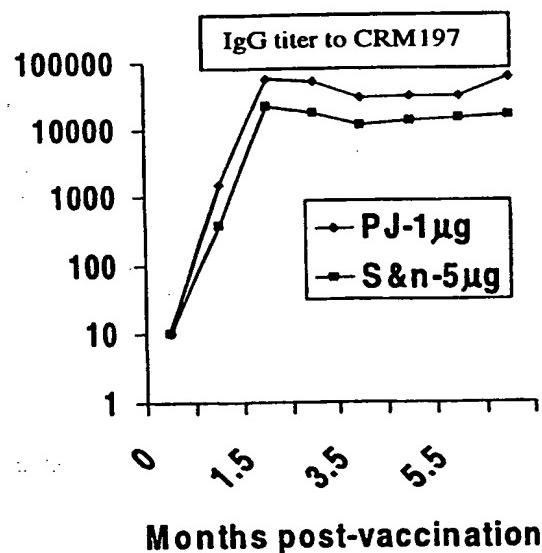
FIG. 6B
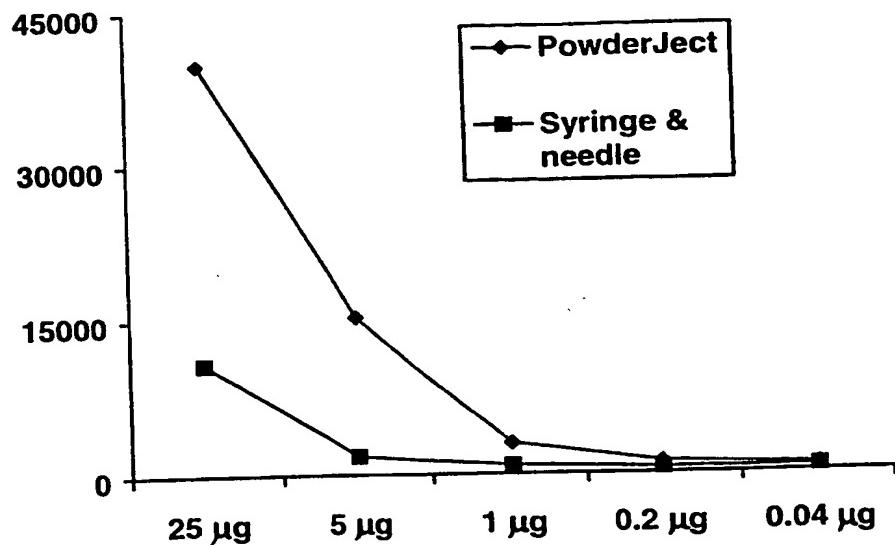
FIG. 7
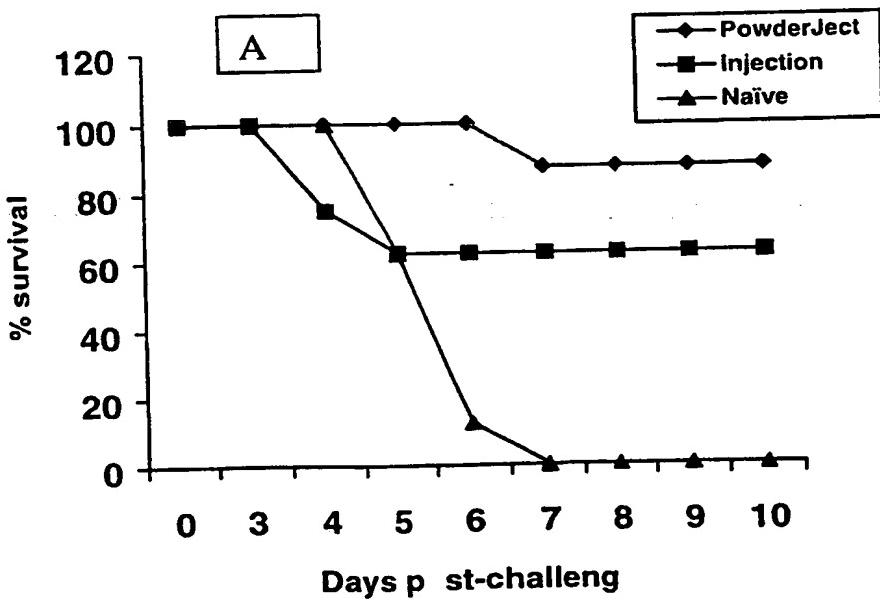
FIG. 8A

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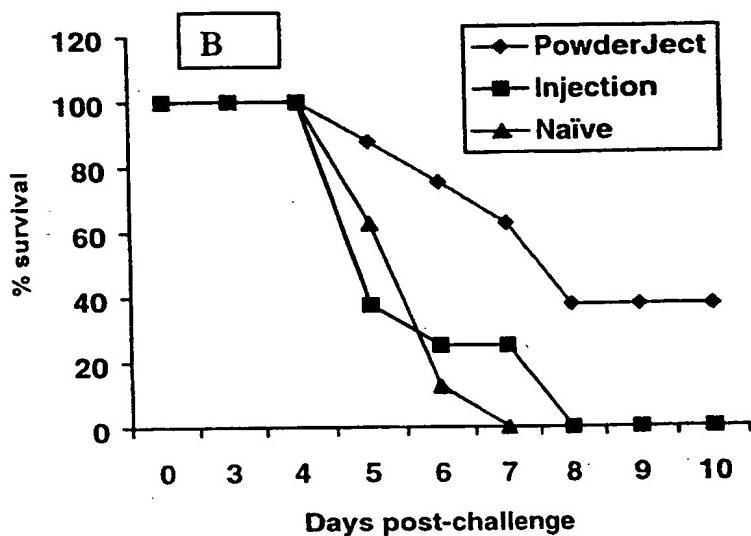
FIG. 8B
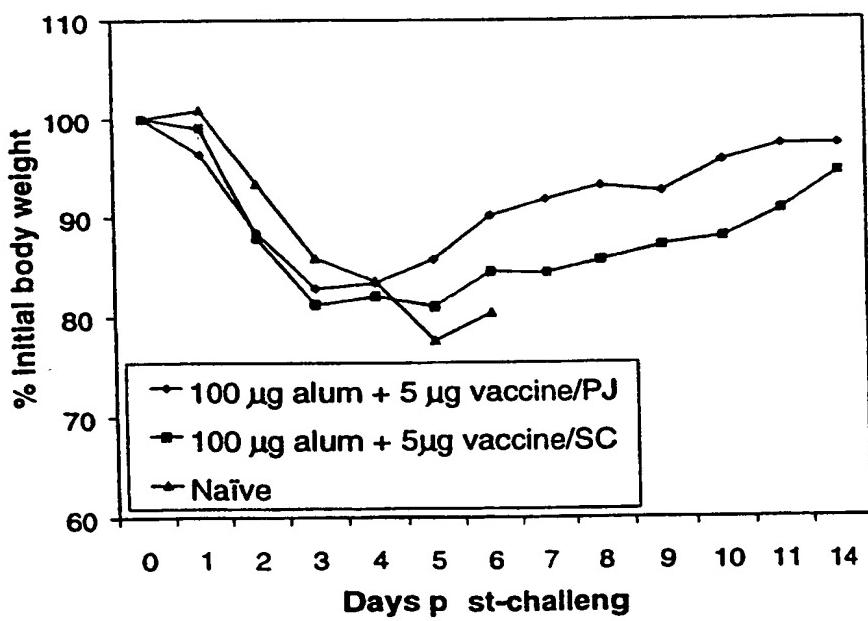
FIG. 9
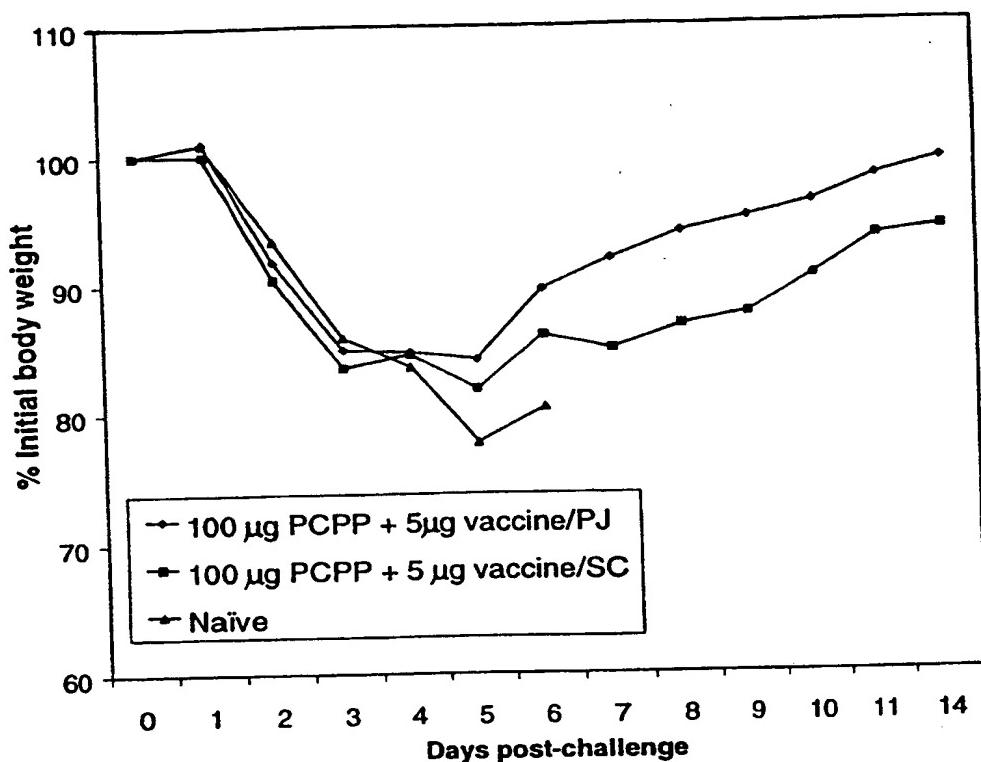
FIG. 10
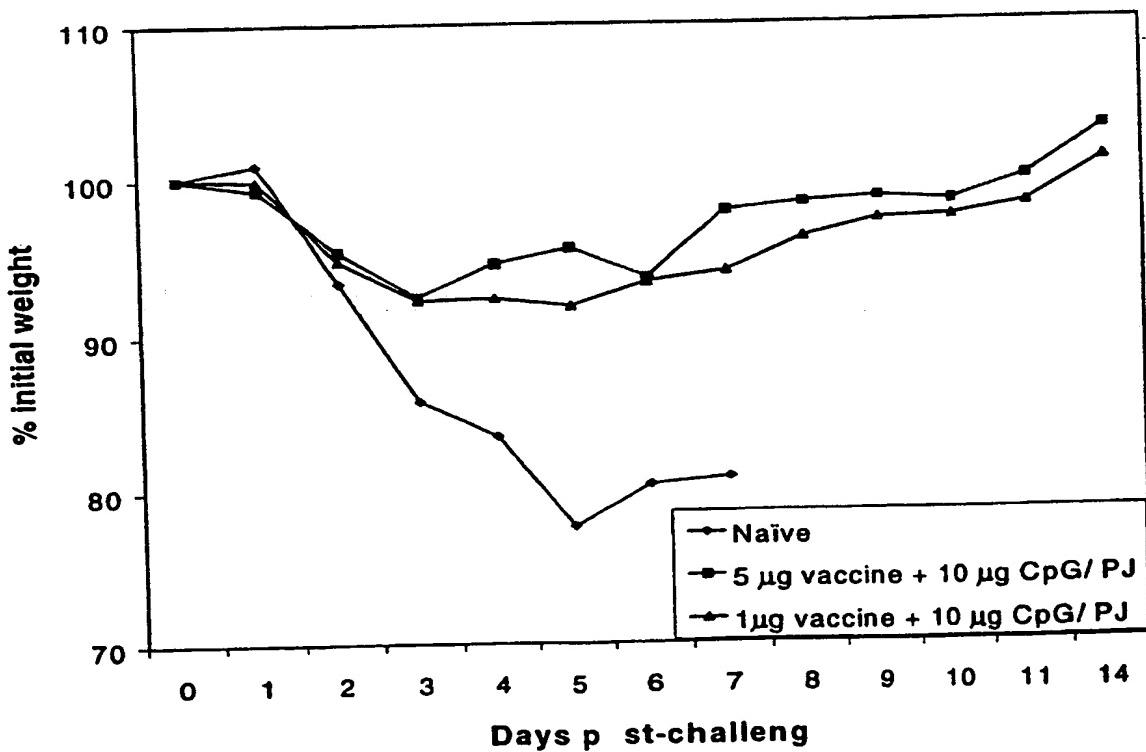
FIG. 11A
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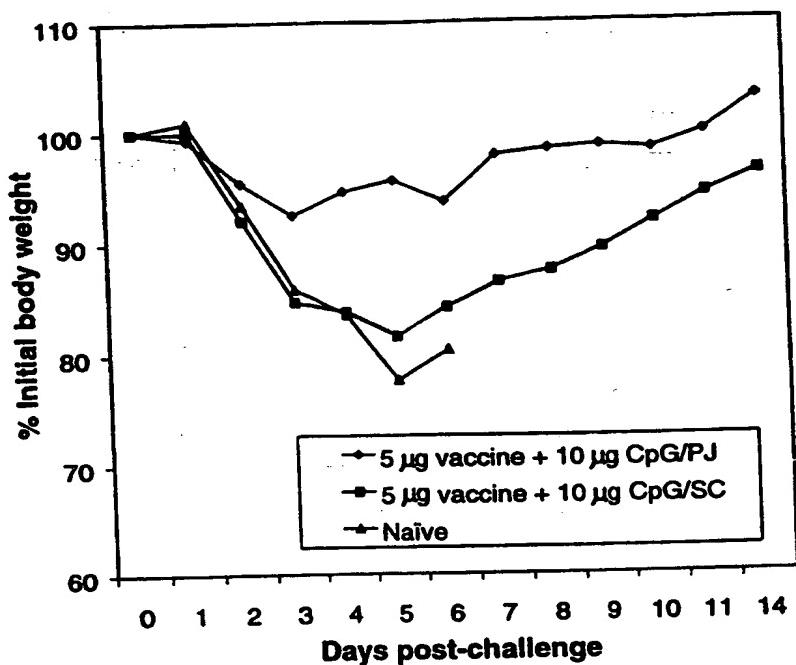
FIG. 11B
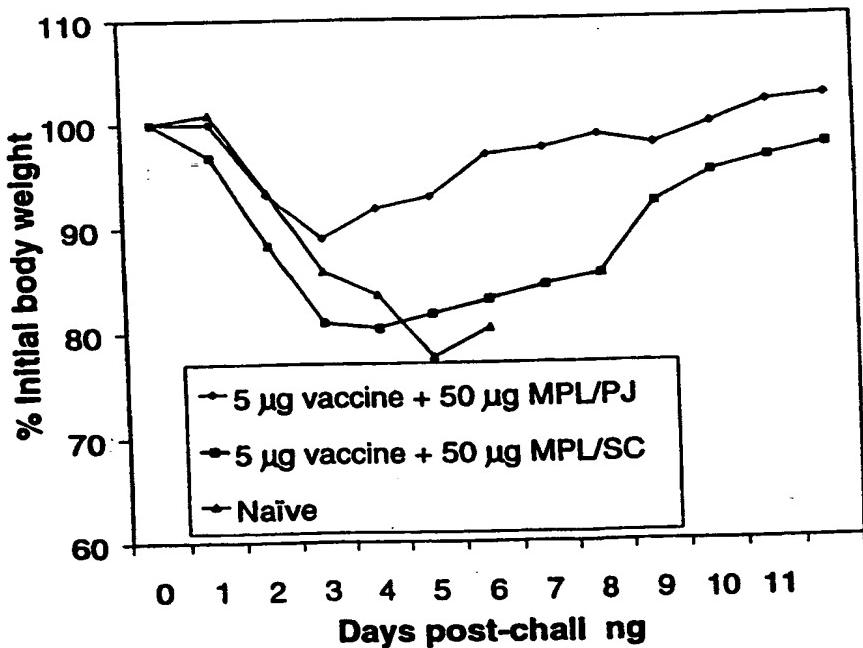
FIG. 12

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   A61K39/39   A61K9/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 90 01949 A (UNIV AUSTRALIAN) 8 March 1990 see page 1, line 32 - page 3, line 31 see page 5, line 6 - line 27 see examples 1,4 --- -/--	1,2, 4-20,24, 26-35, 39-41, 43-52, 56, 59-68,70

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 April 1999	06/05/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Fernandez y Branas,F

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category°	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 091 188 A (HAYNES DUNCAN H) 25 February 1992 see claim 1; example 16 ---	1,2, 4-20,24, 26-35, 39-41, 43-52, 56, 59-68,70
X	WO 94 09819 A (DUNCAN JACQUELINE D) 11 May 1994 see page 5, line 3 - page 6, line 19 see page 10, line 18 - line 22; example 5 see page 22, line 5 - line 14 ---	1,2, 4-20,24, 26-35, 39-41, 43-52, 56-68,70
X	WO 97 40163 A (COLPAN METIN ;SCHORR JOACHIM (DE); BAKER HENRY J (US); SMITH BRUCE) 30 October 1997 see page 12 - page 14 see claims 17-22 ---	1-22, 24-37, 39-54, 56,59-70
X	EP 0 390 435 A (TAKEDA CHEMICAL INDUSTRIES LTD) 3 October 1990 see page 3, line 18-30; examples 1,2,4,5 ---	57
X	"REMINGTON'S PHARMACEUTICAL SCIENCES" 1980 , MARK PUBLISHING COMPANY , PENNSYLVANIA XP002100472 see page 1535 "spray drying" and pages 1483-1484, "freeze drying", especially page 1484 "factors affecting formulation" ---	57
X	US 4 629 782 A (CHAN TAI W ET AL) 16 December 1986 see the whole document ---	39,40, 42,52, 59,60,70
A	SARPHIE D F ET AL: "BIOAVAILABILITY FOLLOWING TRANSDERMAL POWDERED DELIVERY (TPD) OF RADIOLABELED INULIN TO HAIRLESS GUINEA PIGS" JOURNAL OF CONTROLLED RELEASE, vol. 47, no. 1, 7 July 1997, pages 61-69, XP000685875 see the whole document ---	1-70

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